LMSC-D469858

VOLUME II
APPENDIX

FINAL REPORT
LOW COST PROGRAM PRACTICES
FOR
FUTURE NASA SPACE PROGRAMS

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DECEMBER 1975

CONTRACT NAS W-2752

LOCKHEED MISSILES & SPACE COMPANY, INC.
A SUBSIDIARY OF LOCKHEED AIRCRAFT CORPORATION
SPACE SYSTEMS DIVISION • SUNNYVALE, CALIFORNIA

Lockheed Missiles & Space Company

ENGINEERING MEMORANDUM

TITLE: IMPACT OF MIL-D-1000 UPON SPACE PROGRAMS & PROPOSED COST IMPROVEMENTS OF CHANGES.	EM NO: LCPP-2 REF: DATE: January 7/1975.
AUTHORS: H K Burbridge. H K Burbridge	APPROVAL: ENGINEERING SYSTEM ENGRG D L Hannaford

Introduction: MIL-D-1000 Drawings, Engineering & Associated Lists. This Military Specification prescribes general requirements for the preparation of Engineering Drawings & Associated Lists, and for application of Intended Use Categories for their acquisition. The key word to be considered when analysing the impact of MIL-D-1000 is the word general. The specification does indeed set forth its provisions in general terms, but in keeping with current Military Specification practices cites as requirements a whole hierarchy of other specifications and standards. These supplementary documents particularize all of the details which are to be included in the preparation, reproduction, and delivery of drawings the US Government contracts to purchase. LMSC has studied the cost driving aspects of this Military specification in the previous Low Cost Program Practices study, but the study was cursory only, and the cost factors derived were based upon limited data. This analysis of MIL-D-1000 investigates the complex interactions of the entire documentation hierarchy to a much greater level of detail, and furnishes not only cost values based upon actual program experience, but also recommends changes to the extant MIL-D-1000 specification believed essential for improvement of the utility of the document as a means of drawing control.

Historical Background: MIL-D-1000 superseded a previous document MIL-D-70327 as of March 16 1959. MIL-D-70327 had been in use for almost 20 years at that time, but much confusion existed among contractors concerning its application, as it applied essentially to drawings from which small components were made and assembled. No particular standardization of symbology was involved, nor was the requirement for reproducibility of drawings clearly defined. MIL-D-1000 was an attempt upon the part of Military procurement agencies to rectify the faults, and obviate the shortcomings of its predecessor. Unfortunately, the task of preparation was entrusted to Army

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APPENDIX

FINAL REPORT

LOW COST PROGRAM PRACTICES FOR FUTURE NASA SPACE PROGRAMS

15 DEC 1975

Contract NAS W-2752

Prepared for:

NASA Headquarters
Washington, D. C.

Prepared by:

Lockheed Missiles & Space Company, Inc.
Space Systems Division
Sunnyvale, California

FOREWORD

This Volume II is the Appendix to Volume I, Low Cost Program Practices Final Report. As such, it contains those Engineering Memoranda generated during the course of the 18 month LCPP study contract NAS W-2752. EMs #7 and #18 were not included in this Volume by direction from NASA/HQ Low Cost Systems Office (LCSO), hence the breaks in the chronological sequence. All others EMs included follow in ascending numerical order in accordance with the Table of Contents which appears as Page (ii) of this Appendix.

TABLE OF CONTENTS

ENGINEERING MEMORANDUM

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Maintenance Unit cognizance. These agencies were concerned primarily with drawings intended for Maintenance and Logistics operations and support, as pertaining to aircraft, army ground vehicles, and weaponry. The peculiar requirements of space vehicles were not foreseen at the time of MIL-D-1000 preparation and issue, and even at the time of its revision, March 1 1965, no account was taken of the complexities of requirements built into the specification, and their cost impact upon space programs. The primary intended use of the specification was to faciliate procurement by the US Government of Master drawings for production of as many as 150 legible copies of each drawing involved. Further, these Master drawings would be so standardized that all government contractors would be able to produce hardware from a drawing, or set of drawings, regardless of where these had been produced, or by whom. This primary intention has not been very successful.

MIL-D-1000, Forms and Categories: Fig.1. MIL-D-1000 Associated Specifications, Standards, Handbooks & Manuals Tree, depicts graphically, the interdependency and inter-relationship of the many documents comprising the hierarchy invoked by MIL-D-1000. Problems arise when contractors attempt to interpret this specification since there are three Forms implicit in MIL-D-1000, any one of which can be invoked by the procuring agency. Form 1., the most rigorous, imposes the entire hierarchy. Form 2., curtails approximately 50% of the requirements imposed by Form 1., but leaves in force those provisions and requirements causative of the greatest costs to a program; whereas Form 3 negates the requirements of MIL-D-1000 almost entirely, retaining in force only the safeguarding of classified information rqmt, the identification of rights to data provision, and the inspection to assure compliance with instructions clause. Fig.2. lists requirements by category to permit easy comparison.

MIL-D-1000 Cost Driving Provisions: There are two major cost drivers implicit within this specification:

(1) The imposition of MIL-STD-100A Engineering Drawing Practice. This standard is imposed in full when MIL-D-1000 Form 1, is mandated, and is imposed in part, to the degree stated in MIL-D-1000, when Form 2 is specified. MIL-STD-100A is not invoked by Form 3.

(2) MIL-Q-9858A Quality Program Requirements. MIL-D-1000 imposes this specification for all three forms of drawing control, and all drawing categories included in the specification.

Of these two, the second, MIL-Q-9858A is the greater cost driver for most programs, and evidence will follow which indicates that the costs to assure that requirements have been met, almost equal in amount, costs to prepare the drawings required for the program under consideration.

Cost Comparisons Based on Program Data: As has been stated, MIL-D-1000 was intended primarily for use with aircraft drawings where large numbers of reproducibles were to be produced to a given standard, so that large numbers of copies could be obtained per master, and that several different contractors from the one producing the drawings could fabricate hardware from a set of these standard drawings furnished by the Government. Space vehicles often are "one of a kind", and employ end item hardware of a type not envisioned when the Military specification was compiled. Symbology for example, did not exist for items which have been developed for space usage, when MIL-D-1000 was drawn up; and drawing types for printed circuit masters were not included in the classes of drawings governed by application of MIL-STD-100A. The outcome of these deficiencies in the specifcation and standard was that for most space vehicle programs undertaken by aerospace contractors, Form 1 was never imposed. Frrm 2 was the usual method of control as it permits more latitude in the preparation of drawings, and imparts considerably less penalty to tight schedules. Costs of compliance with the requirements of Form 1 are thus almost impossible to acquire.

LMSC has however, undertaken programs requiring Form 1 type of control. One of these was the recently completed YO-3A Quiet Aircraft contract for the US Army. While this is an aircraft, the on-board systems are built to space standards for high reliability parts, long maintenance-free life, and survivability. LMSC considers that this contract shows the trend of costs when full compliance with Form 1 requirements is mandated by a Government contracting agency. For details of these costs see the cost breakdown given in Figure 3. The significant cost driver is evident immediately:

- The cost of quality inspection of the engineering drawings produced was 44.9 of the total drawing costs, which in turn accounted for 10.9 of the total program costs. (Development program only, not production follow-on contract.)
- The program still carries a classification of Secret, so many details cannot be considered in this E.M. However, a good comparison may be made in the area of engineering drawings as complete sets of drawings were furnished to LMSC by the Airframe manufacturer. This manufacturer, a major U.S. supplier of light commercial aircraft provided drawings for the aircraft produced to commercial standards only. These are comparable with drawings produced under Form 3 requirements of MIL-D-1000. A direct comparison is thus available between the costs to produce these drawings, and the costs to re-draw them to conform with Form 1 requirements. LMSC performed the Form 1 drawing production task, all drawings being inked, and rendered on drawing cloth, and in some cases on Mylar.
- The drawings produced on plastic film were used as masters for printed circuits associated with the Night Viewing Aerial Periscope (NVAP).

Cost Impact of Imposing Form 2: The majority of drawing packages produced for space vehicle programs by LMSC, have been prepared to the standards required by MIL-D-1000 Form 2. As stated earlier in this E.M. Form 2 requires that MIL-STD-100A govern the production of drawings and lists, to the extent specified by MIL-D-1000. Practically, this infers that most of the requirements of MIL-STD-100A are forgone, but that the quality assurance activity required to prove that compliance with the requirements has been effected is still in force. Figure 2 shows the complexity associated with this particular Form, versus that associated with Forms 1 & 3. Figure 4 contrasts the costs of drawings, and the quality assurance activity involved in their production for a number of programs undertaken by LMSC over the last 10 years. It must be noted that LMSC is an aerospace contractor, and as such produces drawings under the Form 3 class which are very nearly identical with those produced under the Form 2 class. The major differences are within the categories required to be checked (see figure 2). Similarly, LMSC drawings produced for purely commercial programs closely resemble the Form 3 items.

Cost Drivers, Forms 1 & 2: One of the major contributors to the cost of drawings produced in compliance with Forms 1 & 2 of MIL-D-1000, is the checking function. Drawings produced to both these forms are subjected to checking by a drawing checking department/group whose members seek to eliminate inaccuracies from the drwaings, such as improper dimensions, symbols, misnumbering, wrong call-outs, poor drafting techniques, etc. After the checks- function is completed the Quality Assurance drawing inspectors review the drawings to determine that the drawing and checking functions are indeed completed in accordance with the required standards. Prior to final release of these drawings for use by either the manufacturing process, or the Government, a further quality check is performed by the resident Government Agency Quality Assurance inspector. In-accuracies, non-compliances, or other deficiencies are then rectified to Governmental satisfaction, and again, each dwg

IS SUBJECTED TO YET ANOTHER SCRUTINY PRIOR TO ACCEPTANCE OF THE DRAWINGS. It has proved impossible to determine additional costs to a program which arise from this practice, but it is obvious that in terms of schedule delays, the additional checking functions are both costly, and to a large extent unnecessary. Echelons of checkers add little to the drawing value, but much to its costs, and it is suggested that this practice be discontinued.

Conclusions & Recommendations: Drawing practices in use throughout the aerospace industry tend to be very similar contractor to contractor. Expressed in other terms, contractors deriving a very high proportion of their business from Government Agencies have internal systems for drawing production which conform well with the requirements of MIL-STD-100A. In general, NASA requires drawings to be furnished in conformance with the requirements of MIL-D-1000 Form 2, but in actuality the deliverable drawing is much more likely to conform with Form 3 after all waivers and deviations granted have been incorporated into a contract. Unless NASA intends to purchase drawings and hardware from commercial sources not presently purveying drawings produced to Government standards, it seems unnecessary to impose MIL-D-1000 Form 2 on the aerospace industry. On the other hand, if Form 3 is imposed, there is a minor conflict in that the Quality Provisions of MIL-Q-9858A are still required, and this document is not used by NASA, which employs its own NHB.5300.4(1B).

As has been stated in this E.M., the most feasible approach to drawing control would be for NASA to discontinue the use of MIL-D-1000, and issue a simplified document which could be prepared to incorporate only those drawing controls essential for production of NASA drawings. If this step were taken, NASA would then be a Government Agency using a drawing control document not used by other Government agencies. To obviate this condition, a feasible solution would be for NASA to originate a very simple drawing control document, in cooperation with all other Government Agencies. The aerospace industry could be involved in the production of this document, which when released, would supersede the present MIL-D-1000.

There are several compelling reasons for issuance of a new specification to replace MIL-D-1000. These are:

- o Average costs to produce drawings to MIL-D-1000 Form 1 from the data shown in Fig 4 are approx 11.7% of Total Program Costs (TPC). Average costs of dischargeing the quality assurance functions for these dwgs is 5.5% TPC or 47% of the overall dwg costs.
- o Costs to produce dwgs to MIL-D-1000 Form 2 requirements average 9.2% of total program costs, with the assurance function averaging 4.0%TPC or approx 43% of the dwg production costs
- o Compliance with the minimal requirements imposed by MIL-D-1000 Form 3 averages 6.4% of TPC, and the assurance functions average 1.5% of TPC or approx 23% of the costs to produce such drawings. Were the safeguarding of classified information, identification of rights to data, and the MIL-Q-9858A provisions removed,which is all that this Form imposes, contractors would be employing their own standards of quality assurance. This would reduce the costs of the assurance function to approx 10% of overall dwg costs (See Figure 4 for some commercial programs used as examples).
- o In addition to these values cited above, the benefit of reducing confusion induced by the large number of documents MIl-D-1000 Forms 1 &2 impose, would be realized. Reading time for personnel concerned would be greatly reduced as another benefit.
- o Since MIL-D-1000 and its attendant document MIL-STD-100A were first prepared and released, reproduction methods used to obtain legible copies of drawings have improved considerably. This advance in technique obviates the main need for Forms 1 & 2.

It is strongly recommended that MIL-D-1000 be rescinded as soon as possible, and replaced with a more usable document.

FOLDOUT FRAME 1

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

INVOKED MILITARY STANDARDS.

1

MIL STD 143

SPECIFICATIONS & STANDARDS - ORDER OF PRECEDENCE FOR THE SELECTION OF:

WHERE PROCUREMENT DOCUMENTS DO NOT CITE SPECIFICATIONS & STANDARDS, THE DESIGN ACTIVITY SHALL SELECT THESE AS REQUIRED FROM THE DoDISS :- DEPARTMENT OF DEFENSE INDEX OF SPECIFICATIONS AND STANDARDS, IN THE FOLLOWING ORDER OF PREFERENCE:

- GROUP I — FEDERAL STANDARDS & SPECIFICATIONS
- GROUP II — INDUSTRY STANDARDS & SPECIFICATIONS
- GROUP III — GOVT. STDS & SPECS NOT LISTED IN DoDISS & OTHER THAN MIL & FED SPECS & STDS. EXAMPLES: NASA & FAA.
- GROUP IV — COMPANY STANDARDS & SPECIFICATIONS.

1

MIL STD 100

ENGINEERING DRAWING PRACTICES

Where MIL-D-1000 Form 1 is called out, MIL-STD-100 is to be applied in its entirely.

Where MIL D 1000 Form 2 is called out, MIL STD 100 applies only to the extent specified in MIL-D-1000.

2

3

4 INDUSTRY STDS INVOKED BY MIL-STD-100 CH.5 *

MIL-STD-100 CHAP.5. * 4

USA INDUSTRIAL STANDARDS.ISA
(US INDUSTRIAL STDS ASSOC'N)

STANDARD	CONTROLS
USAS B46.1-62.	SURFACE TEXTURE, SURFACE ROUGHNESS, WAVINESS & LAY.
USAS Y14.5-66.	DIMENSIONING & TOLERANCING for Engin'rg dwgs.
USAS Y14.15-66.	ELECTRICAL & ELECTRONICS DIAGRAMS.
USAS Y32.2-67.	GRAPHIC SYMBOLS for Electrical & Electronic diagrams.
USAS Y32.16-65.	ELECTRICAL & ELECTRONIC REFERENCE DESIGNATIONS.
AWS-STD A2.0-58	WELDING SYMBOLS
AWS-STD A2.2-58	NON-DESTRUCTIVE TESTING, WELDS.

SECONDARY
MIL STDS INVOC[illegible]

MIL STD	
MIL-STD-9	SCREW THREADS [illegible]
MIL-STD-12C	ABBREVIATIONS [illegible]
MIL-STD-14	ARCHITECTURAL [illegible]
MIL-STD-17	MECHANICAL SY[illegible]
MIL-STD-18	STRUCTURAL SY[illegible]
MIL-STD-29	SPRINGS, MECHA[illegible]
MIL-STD-34	OPTICAL ELEM[illegible]
MIL-STD-106	MATHEMATICAL S[illegible]
MIL-STD-275	PRINTED WIRING[illegible]
MIL-STD-806	LOGIC DIAGRAM[illegible]

5

MILITARY HANDBOOKS

HANDBOOK	SUBJECT
H4-1	FEDERAL SUPPLY CODE for Manufacturers (name to code)
H4-2	FEDERAL SUPPLY CODE for Manufacturers (code to name)
H6-1	FEDERAL ITEM IDENTIFICATION GUIDE, for supply - cataloging
H7	MANUFACTURERS' PART & DRAWING NUMBERING SYSTEM for use in the Federal cataloging system.

3

MILITARY MANUALS

MANUAL	SUBJECT
5220.22-M	DoD INDUSTRIAL SECURITY MANUAL for safeguarding Classified Information.
4120-M	STANDARDIZATION POLICIES, PROCEDURES, & INSTRUCTIONS.

4

MIL-STD-100 CITED REQUIREMENTS

Chapter	Title		Appendix

FOLDOUT FRAME 2

MIL-D-1000, ASSOCIATED SPECIFICATIONS, STANDARDS, HANDBOOKS, AND MANUALS TREE

MIL-D-1000

MILITARY SPECIFICATION

DRAWINGS, ENGINEERING & ASSOCIATED LISTS

FORMS OF DRAWINGS

FORM 1: DRAWINGS TO MILITARY STANDARDS. FULL CONFORMANCE WITH MIL-STD-100. CONTRACT SPECIFIES GOVT. CODE IDENTIFICATION, AND DOCUMENT NUMBERS IF THESE ARE TO BE ASSIGNED.

FORM 2. DRAWINGS TO INDUSTRY STANDARDS (PARTIAL MILITARY CONTROL). PREPARED TO CONTRACTORS' NORMAL DRAFTING STANDARDS, & TO RQMTS LISTED AS FOLLOWS:

- CONTAIN ENGIN'RG DATA FOR STATED CATEGORY.
- CODE IDENTIFIED BY NUMBER PER MIL-STD-100
- MEET LEGIBILITY & PRODUCIBILITY RQMTS PER PARA 3.14 MIL-D-1000
- MEET ITEM IDENT. DWG, & PART NUMBERING PER MIL-STD-100
- MEET RQMTS OF "CHANGES REQUIRING NEW IDENT'N. PER MIL-STD-100
- CROSS REFERENCE CONTRACTORS' SYMBOLS TO GOVT.STD. IN DOC'MT TO GOVT. WHERE STD IS AVAILABLE. WHERE NOT EXPLAIN SYMBOLS ETC ON DWG.
- IDENTIFY INTERFACE, SPECIFICATION, AND SOURCE CONTROL DWGS PER MIL-STD-100.

FORM 3: DWGS TO INDUSTRY STANDARDS (MINIMUM MILITARY CONTROL). PREPARED TO CONTRACTOR'S NORMAL DRAFTING PRACTICE & PER THE CATEGORY SPECIFIED.

CATEGORIES:

A. DESIGN EVALUATION. TO EVALUATE DESIGNS OR DOCUMENT R&D WORK
B. INTERFACE CONTROL. TO EVALUATE AND CONTROL INTERFACE BETWEEN INTERRELATED COMPONENTS, SUBSYSTEMS, OR SYSTEMS.
C. SERVICE TEST. TO SUPPORT A GOVERNMENT SERVICE TEST OF MATERIEL.
D. LOGISTICS SUPPORT. TO SUPPORT LOGISTICS FUNCTIONS SUCH AS
   - PROVISIONING
   - CATALOGING
   - ITEM IDENTIFICATION
   - SOURCE CODING
   - STANDARDIZATION
E. PROCUREMENT. (IDENTICAL ITEMS) TO PERMIT MANUFACTURE OF ITEMS THAT ARE SUBSTANTAILLY IDENTICAL TO ORIGINAL ITEMS (INCL IDENTICAL REPAIR PARTS).
F. PROCUREMENT. (INTERCHANGEABLE ITEMS) TO PERMIT PROCUREMENT OF ITEMS THAT ARE INTERCHANGEABLE WITH, BUT NOT NECESSARILY IDENTICAL TO, ORIGINAL ITEMS SUCH AS INTERCHANGEABLE ASSEMBLIES OR SPARE PARTS.
G. INSTALLATION. TO EFFECT OPERATIONAL INSTALLATION OF PARTS, COMPONENTS, EQUIPMENTS, SUBSYSTEMS, OR SYSTEMS.
H. MAINTENANCE. TO PROVIDE MAINTENANCE INFORMATION, AND PERMIT OVERHAUL OF MATERIEL, EQUIPMENT, SUBSYSTEMS, AND SUBSYSTEMS.
I. GOVERNMENT MANUFACTURE. TO PROVIDE INFORMATION FOR MANUFACTURE OF DESIGNATED PARTS BY THE GOVERNMENT.
J. INTERCHANGEABILITY CONTROL. TO IDENTIFY, AND CLASSIFY ITEMS FOR INTERCHANGEABILITY, SUBSTITUTABILITY, AND REPLACEABILITY CONTROL (*SEE MIL-I-8500)

...00 is to be applied

...00 applies only to

2

SECONDARY

MIL STDS INVOKED

MIL STD	CONTROLS
MIL-STD-9	SCREW THREADS & Methods of specifying them.
MIL-STD-12C	ABBREVIATIONS for use on drawings, & in technical type publications & official lists.
MIL-STD-14	ARCHITECTURAL SYMBOLS.
MIL-STD-17	MECHANICAL SYMBOLS.
MIL-STD-18	STRUCTURAL SYMBOLS.
MIL-STD-29	SPRINGS, MECHANICAL: Dwg requirements for.
MIL-STD-34	OPTICAL ELEMENTS. Preparation of dwgs for optical elements, & Optical systems; gen'l rqmts for
MIL-STD-106	MATHEMATICAL SYMBOLS.
MIL-STD-275	PRINTED WIRING for electronic equipment, stds.
MIL-STD-806	LOGIC DIAGRAMS: Stds for preparation

2

FED

FEDERAL SPECIFICATIONS

UU-P-00561..	Paper Tracing.
	Sets forth the standards which must be met by paper used to prepare dwgs for the Govt, and the standards used for purchase of dwg paper by the Govt. for its own use.
CCC-C-531..	Cloth, Tracing.
	Sets forth the standards used by the Govt to purchase tracing cloth, and to be used by contractors producing dwgs on tracing cloth, destined for Govt use.

2

MIL

INVOKED SPECIFICATIONS (MILITARY)

MIL-D-5480	DATA, ENGINEERING & TECHNICA...
	REPRODUCTION REQUIREMENTS FOR ... CITES REQUIREMENTS FOR THE R... DUCTION of Engineering Data ... terms of: Copy Format, Repro... -Formatting for Masters, Con... of copies and storage of ...
MIL-M-9868	Microfilming of Engineering ... 35mm, Requirements for:
	Sets forth the requirements ... when microfilming documents ... Use; ie frame size, format... cropping, pages per frame ...
MIL-Q-9858A	Quality Program Requirements...
	Sets ... the inspection std... go/no-go criteria by which ... destined for the Govt are ... quality controlled, accept...

-100 CITED REQUIREMENTS

Synopsis

See Below.

AME 2

FOLDOUT FRAME 3

MIL-D-1000, ASSOCIATED SPECIFICATIONS, STANDARDS, HANDBOOKS, AND MANUALS TREE

MIL-D-1000

MILITARY SPECIFICATION

DRAWINGS, ENGINEERING & ASSOCIATED LISTS

RAWINGS

RAWINGS TO MILITARY STANDARDS. FULL CONFORMANCE WITH MIL-STD-100.
ONTRACT SPECIFIES GOVT. CODE IDENTIFICATION, AND DOCUMENT NUMBERS
IF THESE ARE TO BE ASSIGNED.
RAWINGS TO INDUSTRY STANDARDS (PARTIAL MILITARY CONTROL). PREPARED TO
CONTRACTORS' NORMAL DRAFTING STANDARDS, & TO RQMTS LISTED AS FOLLOWS:

- CONTAIN ENGIN'RG DATA FOR STATED CATEGORY.
- CODE IDENTIFIED BY NUMBER PER MIL-STD-100
- MEET LEGIBILITY & PRODUCIBILITY RQMTS PER PARA 3.14 MIL-D-1000
- MEET ITEM IDENT. DWG, & PART NUMBERING PER MIL-STD-100
- MEET RQMTS OF CHANGES REQUIRING NEW IDENT'N. PER MIL-STD-100
- CROSS REFERENCE CONTRACTORS' SYMBOLS TO GOVT.STD. IN DOC'MT TO GOVT. WHERE STD IS AVAILABLE. WHERE NOT EXPLAIN SYMBOLS ETC ON DWG.
- IDENTIFY INTERFACE, SPECIFICATION, AND SOURCE CONTROL DWGS PER MIL-STD-100.

DWGS TO INDUSTRY STANDARDS (MINIMUM MILITARY CONTROL).
PREPARED TO CONTRACTOR'S NORMAL DRAFTING PRACTICE & PER THE CATEGORY
SPECIFIED.

CATEGORIES:

A. DESIGN EVALUATION. TO EVALUATE DESIGNS OR DOCUMENT R&D WORK
B. INTERFACE CONTROL. TO EVALUATE AND CONTROL INTERFACE BETWEEN INTERRELATED COMPONENTS, SUBSYSTEMS, OR SYSTEMS.
C. SERVICE TEST. TO SUPPORT A GOVERNMENT SERVICE TEST OF MATERIEL.
D. LOGISTICS SUPPORT. TO SUPPORT LOGISTICS FUNCTIONS SUCH AS
   - PROVISIONING
   - CATALOGING
   - ITEM IDENTIFICATION
   - SOURCE CODING
   - STANDARDIZATION
E. PROCUREMENT. (IDENTICAL ITEMS) TO PERMIT MANUFACTURE OF ITEMS THAT ARE SUBSTANTAILLY IDENTICAL TO ORIGINAL ITEMS (INCL IDENTICAL REPAIR PARTS).
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H. MAINTENANCE. TO PROVIDE MAINTENANCE INFORMATION, AND PERMIT OVERHAUL OF MATERIEL, EQUIPMENT, SUBSYSTEMS, AND SUBSYSTEMS.
I. GOVERNMENT MANUFACTURE. TO PROVIDE INFORMATION FOR MANUFACTURE OF DESIGNATED PARTS BY THE GOVERNMENT.
J. INTERCHANGEABILITY CONTROL. TO IDENTIFY, AND CLASSIFY ITEMS FOR INTERCHANGEABILITY, SUBSTITUTABILITY, AND REPLACEABILITY CONTROL (*SEE MIL-I-8500)

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FEDERAL SPECIFICATIONS

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	Sets forth the standards which must be met by paper used to prepare dwgs for the Govt, and the standards used for purchase of dwg paper by the Govt. for its own use.
CCC-C-531..	Cloth, Tracing.
	Sets forth the standards used by the Govt to purchase tracing cloth, and to be used by contractors producing dwgs on tracing cloth, destined for Govt use.

INVOKED SPECIFICATIONS
(MILITARY)

MIL-D-5480	DATA, ENGINEERING & TECHNICAL:
	REPRODUCTION REQUIREMENTS FOR: CITES REQUIREMENTS FOR THE REPRODUCTION of Engineering Data in terms of: Copy Format, Repro-Formatting for Masters, Control of copies and storage of masters etc.
MIL-M-9868	Microfilming of Engineering Documents, 35mm, Requirements for:
	Sets forth the requirements to be met when microfilming documents for Govt Use; ie frame size, formatting, cropping, pages per frame etc.
MIL-Q-9858A	Quality Program Requirements.
	Sets the inspection stds, and go/no-go criteria by which dwgs destined for the Govt are to be quality controlled, accepted/rejected.

MIL STD 143

SPECIFICATIONS & STANDARDS - ORDER OF PRECEDENCE FOR THE SELECTION OF:

WHERE PROCUREMENT DOCUMENTS DO NOT CITE SPECIFICATIONS & STANDARDS, THE DESIGN ACTIVITY SHALL SELECT THESE AS REQUIRED FROM THE DoDISS:- DEPARTMENT OF DEFENSE INDEX OF SPECIFICATIONS AND STANDARDS, IN THE FOLLOWING ORDER OF PREFERENCE:

GROUP I	FEDERAL STANDARDS & SPECIFICATIONS
GROUP II	INDUSTRY STANDARDS & SPECIFICATIONS
GROUP III	GOVT. STDS & SPECS NOT LISTED IN DoDISS & OTHER THAN MIL & FED SPECS & STDS. EXAMPLES: NASA & FAA.
GROUP IV	COMPANY STANDARDS & SPECIFICATIONS.

MIL STD 100

ENGINEERING DRAWING PRACTICES

Where MIL-D-1000 Form 1 is called out, MIL-STD-100 is to be applied in its entirety.

Where MIL D 1000 Form 2 is called out, MIL STD 100 applies only to the extent specified in MIL-D-1000.

2

USA INDUSTRIAL STANDARDS.ISA
(US INDUSTRIAL STDS ASSOC'N)

STANDARD	CONTROLS
USAS B46.1-62.	SURFACE TEXTURE, SURFACE ROUGHNESS, WAVINESS & LAY.
USAS Y14.5-66.	DIMENSIONING & TOLERANCING for Engin'rg dwgs.
USAS Y14.15-66.	ELECTRICAL & ELECTRONICS DIAGRAMS.
USAS Y32.2-67.	GRAPHIC SYMBOLS for Electrical & Electronic diagrams.
USAS Y32.16-65.	ELECTRICAL & ELECTRONIC REFERENCE DESIGNATIONS.
AWS-STD A2.0-58	WELDING SYMBOLS
AWS-STD A2.2-58	NON-DESTRUCTIVE TESTING, WELDS.

3

4 INDUSTRY STDS INVOKED BY MIL-STD-100 CH.5 *

MIL-STD-100 CHAP.5. * 4

SECONDARY

MIL STDS INVOKED

MIL STD	CONTROLS
MIL-STD-9	SCREW THREADS & Methods of specifying them.
MIL-STD-12C	ABBREVIATIONS for use on drawings, & in technical type publications & official lists.
MIL-STD-14	ARCHITECTURAL SYMBOLS.
MIL-STD-17	MECHANICAL SYMBOLS.
MIL-STD-18	STRUCTURAL SYMBOLS.
MIL-STD-29	SPRINGS, MECHANICAL: Dwg requirements for.
MIL-STD-34	OPTICAL ELEMENTS. Preparation of dwgs for optical elements, & Optical systems; gen'l rqmts
MIL-STD-106	MATHEMATICAL SYMBOLS.
MIL-STD-275	PRINTED WIRING for electronic equipment.
MIL-STD-806	LOGIC DIAGRAMS: Stds for preparation

MILITARY HANDBOOKS

HANDBOOK	SUBJECT
H4-1	FEDERAL SUPPLY CODE for Manufacturers (name to code)
H4-2	FEDERAL SUPPLY CODE for Manufacturers (code to name)
H6-1	FEDERAL ITEM IDENTIFICATION GUIDE, for supply - cataloging
H7	MANUFACTURERS' PART & DRAWING NUMBERING SYSTEM for use in the Federal cataloging system.

3

MILITARY MANUALS

MANUAL	SUBJECT
5220.22-M	DoD INDUSTRIAL SECURITY MANUAL for safeguarding Classified Information.
4120-M	STANDARDIZATION POLICIES, PROCEDURES, & INSTRUCTIONS.

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MIL-STD-100.CITED REQUIREMENTS

Chapter	Title	Synopsis
1	General Practices	See Below.
Sec.1.	Engr Dwg Formats.	Lines, Margins, Lettering, Microfilm Alignment, Zoning, Toleranceing, Sizing, Continuation sheets
Sec.2.	Gen'l Dwg Practice	Gen'l Practices for: Flat & Roll Sizes, Numbering Dimensioning, Projections, Partial-views, 3 View Dwgs, Line Characteristics, Special, & Separate Sheets for Sectional Views, Sectioning details, Scales, Linear Examples.
Sec.3.	Numbering, Coding, & Identification	Verbiage for Lists, & Revisions, Parts Lists Identification & numbering, Specification Control Dwgs (SCDs) Release & Preparation, Identificaton for Installation Dwgs, Indeterminate Support Dwgs, Identification & preparation Sequence Diagrams.
Sec.4.	Drawing Titles.	Titling & Block Designators, Letter Sizes for Titles, Title Preparation by Subject, Subordination Procedures.
Sec.5.	Revision of Engr'g Dwgs.	Revision Procedures, Supercession Procedures, Identification rqmts, Release procedures, Duplications, etc.
2.	Types of Engrg Dwgs.	Drawings by Type. Actual Examples, Projections, Multiple Views, Exploded Views, Sectionals, Diagrams, Schematics, etc.
3.	Associated Lists.	Types of Lists, Preparation of Lists, Codes for Lists, Numbering Ordering & Sequencing for Lists.
4.	Definitions of Terms.	Terminology used with drawings defined.
5.	Abbreviations & Symbology.	* Abbreviations & Symbols Approved for use with dwgs. Listings & Definitions of same.
		* (References and invokes all secondary mil stds & industrial-stds)

FOLDOUT FRAME 4

- CROSS REFERENCE CONTRACTORS' SYMBOLS TO GOVT STD. IN DOC'NT TO GOVT. WHERE STD IS AVAILABLE. WHERE NOT EXPLAIN SYMBOLS ETC ON DWG.
- IDENTIFY INTERFACE, SPECIFICATION, AND SOURCE CONTROL DWGS PER MIL-STD-100.

FORM 3: DWGS TO INDUSTRY STANDARDS (MINIMUM MILITARY CONTROL). PREPARED TO CONTRACTOR'S NORMAL DRAFTING PRACTICE & PER THE CATEGORY SPECIFIED.

E. PROCUREMENT. (IDENTICAL ITEMS) TO PERMIT MANUFACTURE OF ITEMS THAT ARE SUBSTANTIALLY IDENTICAL TO ORIGINAL ITEMS (INCL IDENTICAL REPAIR PARTS).

F. PROCUREMENT. (INTERCHANGEABLE ITEMS) TO PERMIT PROCUREMENT OF ITEMS THAT ARE INTERCHANGEABLE WITH, BUT NOT NECESSARILY IDENTICAL TO, ORIGINAL ITEMS SUCH AS INTERCHANGEABLE ASSEMBLIES OR SPARE PARTS.

G. INSTALLATION. TO EFFECT OPERATIONAL INSTALLATION OF PARTS, COMPONENTS, EQUIPMENTS, SUBSYSTEMS, OR SYSTEMS.

H. MAINTENANCE. TO PROVIDE MAINTENANCE INFORMATION, AND PERMIT OVERHAUL OF MATERIEL, EQUIPMENT, SUBSYSTEMS, AND SUBSYSTEMS.

I. GOVERNMENT MANUFACTURE. TO PROVIDE INFORMATION FOR MANUFACTURE OF DESIGNATED PARTS BY THE GOVERNMENT.

J. INTERCHANGEABILITY CONTROL. TO IDENTIFY, AND CLASSIFY ITEMS FOR INTERCHANGEABILITY, SUBSTITUTABILITY, AND REPLACEABILITY CONTROL (*SEE MIL-I-8500)

2 FED

2 MIL

...DS

...f specifying them. ...drawings, & in ...type publications & ...lists.

...requirements for. ...ration of dwgs for ...al elements, & Optic... ...stems; gen'l rqts for

...tronic equipment, stds. ...r preparation

FEDERAL SPECIFICATIONS

UU-T-00561..	Paper Tracing.
	Sets forth the standards which must be met by paper used to prepare dwgs for the Govt, and the standards used for purchase of dwg paper by the Govt. for its own use.
CCC-C-531..	Cloth, Tracing.
	Sets forth the standards used by the Govt to purchase tracing cloth, and to be used by contractors producing dwgs on tracing cloth, destined for Govt use.

INVOKED SPECIFICATIONS (MILITARY)

MIL-D-5480	DATA, ENGINEERING & TECHNICAL; REPRODUCTION REQUIREMENTS FOR:
	CITES REQUIREMENTS FOR THE REPRODUCTION of Engineering Data in terms of: Copy Format, Repro-Formatting for Masters, Control of copies and storage of masters etc.
MIL-M-9868	Microfilming of Engineering Documents, 35mm, Requirements for:
	Sets forth the requirements to be met when microfilming documents for Govt Use; ie frame size, formatting, cropping, pages per frame etc.
MIL-Q-9858A	Quality Program Requirements.
	Sets the inspection stds, and go/no-go criteria by which dwgs destined for the Govt are to be quality controlled, accepted/rejected.

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...trol ...tion ...Dwgs, ...ns. ...r ...in-

...ons,

...for ...Lists.

...th ...ds &

FOLDOUT FRAME 5

KEY: BRANCHES MARKED 1 DENOTE THE PRIMARY MILITARY STANDARDS CALLED OUT BY MIL-D-1000 (FORMS 1 & 2 ONLY)

BRANCHES MARKED "2" DENOTE THE SECONDARY MILITARY SPECIFICATIONS & STANDARDS, AS WELL AS THE FEDERAL SPECIFICATIONS, ALL OF WHICH ARE INVOKED BY THE ACTIONS REQUIRED TO COMPLY WITH MIL-STD-100

BRANCHES MARKED "3" ARE THE INDUSTRIAL STANDARDS, MILITARY HANDBOOKS, AND MILITARY MANUALS INVOKED AS REQUIREMENTS OF COMPLIANCE WITH MIL-STD-100

THE BRANCH MARKED "4" LISTS THE CITED REQUIREMENTS OF THE 5 CHAPTERS OF MIL-STD-100. A SYNOPSIS OF EACH SECTION OF CHAPTER 1, AND EACH SUBSEQUENT CHAPTER, 2-5, IS GIVEN TOGETHER WITH THE CHAPTER HEADING/TITLE.

MAJOR PREPARATION REQUIREMENTS	FORM I	FORM 2	FORM 3
o DRAWING FORMATS PER MIL-STD-100	M	C	C
o DRAWING PRACTICES PER MIL-STD-100	M	C	C
o DIMENSIONING PER MIL-STD-100	M	C	C
o NUMBERING AND CODING PER MIL-STD-100 (INCLUDES REIDENTIFICATION RULES)	M	M	C
o DRAWING TITLES PER MIL-STD-100	M	C	C
o REVISIONS PER MIL-STD-100	M	C	C
o TYPES OF DRAWINGS PER MIL-STD-100	M	R (CONTROL DWGS ONLY)	C
o ASSOCIATED LISTS PER MIL-STD-100	M	C	C
o ABBREVIATIONS AND SYMBOLS PER MIL-STD-100	M	C	C
o USE OF MIL SPECS AND STDS	M	C	C
o ALTERED OR SELECTED ITEM DWGS	M	M	C
o MATERIALS FOR DRAWINGS	M	M	C
o SAFEGUARDING CLASSIFIED INFORMATION ✓	M	M	C
o IDENTIFICATION OF RIGHTS TO DATA ✓	M	M	M
o ORDER OF PRECEDENCE OF SPECS AND STDS PER MIL-STD-143	M	M	M
o INSPECTION AND TEST REQUIREMENTS	M	M	C
o IDENTIFICATION MARKING REQUIREMENTS	M	M	C
o LEGIBILITY AND REPRODUCIBILITY PER MIL-D-5480/MIL-M-9868	M	M	C
o QUALITY ASSURANCE PROVISIONS PER MIL-Q-9858	M	M	C
	M	M	M

M = MILITARY SPECS   C = CONTRACTOR'S NORMAL PRACTICES

Fig. 2. Comparison of the Three (3) Forms Cited by MIL-D-1000

COST BREAKDOWN YO-3A

Program Cost Element	Percent total Program Costs
Program Management	3.5
Engineering Design	23.5
System Engineering & Integration	12.5
Manufacturing	17.0
Tooling	4.2
Test (Including Airworthiness)	9.9
Ground Support Equipment	5.5
Product Assurance (Rel, Safety, Q.E. & Inspection)	11.7
Technical Publications (Including A/C manuals)	5.2
Field Support (Foreign).	7.0
	100.0%

Sub-Breakdown

Overall Engineering Costs Total	36.0	
Engineering & Production Dwgs to MIL-D-1000 Form 1. Total →	$\boxed{10.9}$	(a)
Drawing Inspection & Verification by Q.A.	4.9	(b)

Note: Item (a) includes item (b). Item (b) represents approx 45% of item (a)

Fig. 3. Cost Breakdown YO-3A Program

TYPICAL DRAWING COSTS FOR MIL-D-1000 FORMS

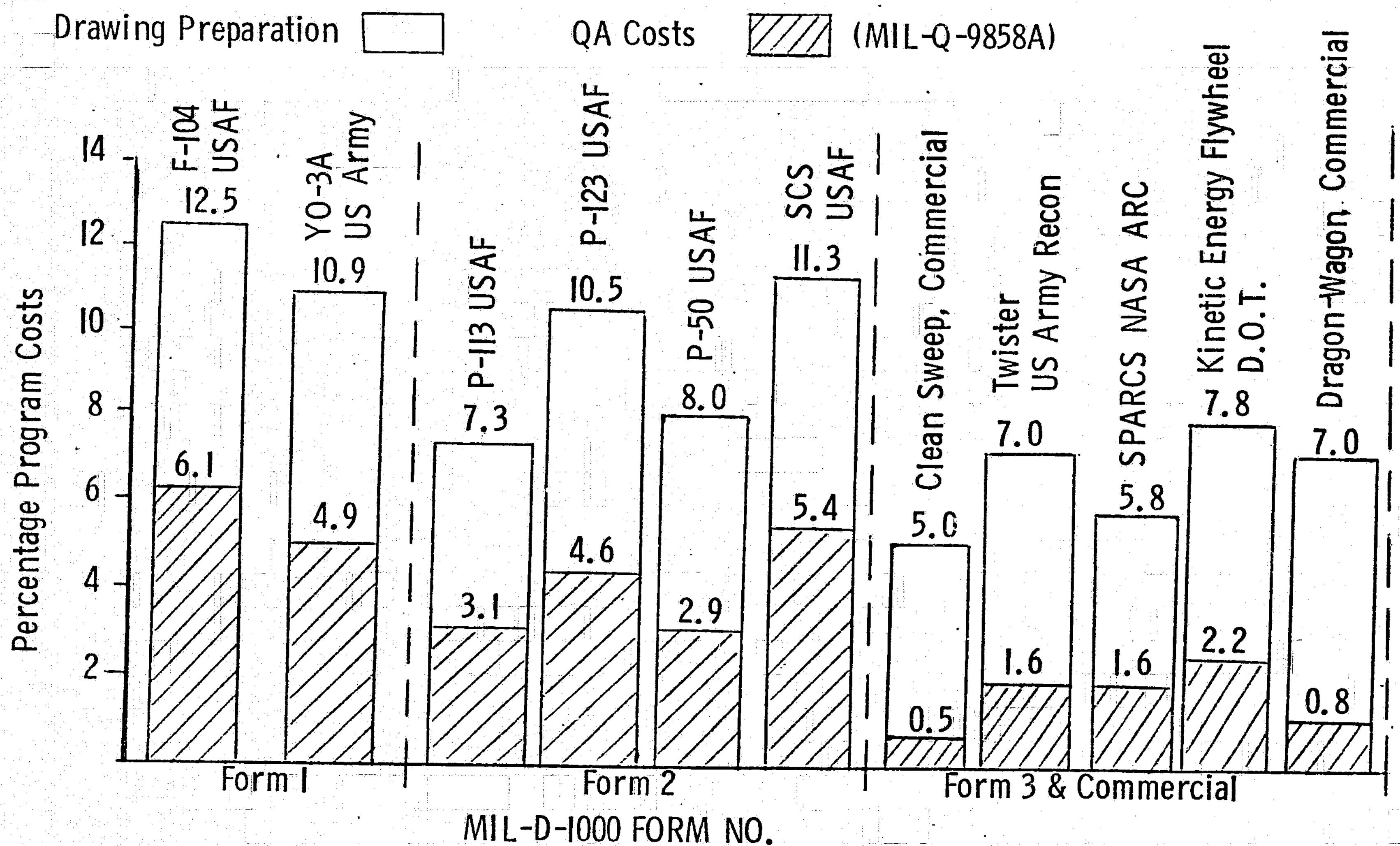


FIGURE 4

Lockheed Missiles & Space Company

ENGINEERING MEMORANDUM

TITLE: Potential Cost Benefits Derivable from Changes to 10 Selected Cost Driving Specifications.	EM NO: LCPP-3 REF: DATE: January 14.1975
AUTHORS: H K Burbridge	APPROVAL: ENGINEERING SYSTEM ENGRG D L Hannaford

As a task of the first LCPP study, 20 cost driving specifications were studied in terms of their requirements, and the degree to which program costs are affected by invocation of these specifications. Each specification selected was examined to determine the cost driving aspects of its requirements, and these cost drivers were listed together with a brief resume of the specification's subject matter.

A task in this study has been the selection of 10 of the original 20 specifications, the prescription of changes whose adoption would mitigate the costs each specification causes when invoked, and the estimation of cost savings which might arise from applying the modified specifications to two typical space programs.

For ease of reference, the tabulation of the 20 cost driving specifications is included in this E.M. and forms pages 2-6 inclusive. The 10 examples selected for study in terms of program cost benefits arising from cost reducing revisions to their requirements are listed below as follows:

(1)	NHB 5300.4(1A)	Reliability Program Requirements
(2)	NHB 5300.4(1B)	Quality Program Requirements
(3)	NHB 5300.4(1C)	Inspection Requirements
(4)	NHB 5300.4(3A)	Rqmts for Soldered Electrical Connections
(5)	NHB 6000.1(1A)	Packaging Requirements
(6)	MIL-STD-883	Test Methods
(7)	NPC 500.1	Configuration Management
(8)	MIL-STD-810B	Environmental Test Methods
(9)	MIL-I-8500	Interchangeability Requirements
(10)	MIL-D-1000	Drawings Engineering, and Associated Lists

(The prefix NHB denotes NASA handbook and is a compilation of several specifications regulating various aspects of a major discipline. For example, the 5300.4 series incorporates those specifcations dealing with the discipline of Product Assurance.)

<u>Assumptions</u>: Three assumptions were necessary to permit this cursory study to be undertaken:

(1) Imposition of a specification upon the two typical programs was for the entire spectrum of requirements. Frequently space programs have been conducted with either parts of a given specification invoked, or the spectrum of requirements has been subjected to modification

NASA/MIL #	SUBJECT	SYNOPSIS
NHB 5300.4(1A)	Reliability Program	Defines: Requirements in the following reliability areas: (1) Reliability Program Management (2) Reliability Engineering (3) Reliability Testing & Evaluation. Implementation: Through contract statement or SOW Cost Drivers: o Requires a High Rel Parts Program o Requires Reliability Demonstration o Requires elaborate failure investigation o Requires program plan & reporting
NHB 5300.4(1B)	Quality Program	Defines: Requirements in the following areas:... (1) Management (2) Design & Development (3) Data Retrieval (4) Procurement (5) Fabrication (6) Inspection & Tests (7) Materials & Non-Conforming Articles (8) Metrology (9) Stamp Control (10) Packaging (11) Sample Planning (12) Government Property Control Implementation: Through contract statement, or SOW
NHB 5300.4(1C)	Inspection (Program) System Provisions for Aeronautical/Space System Materials, Parts Components and Service	This publication sets forth Inspection system requirements for the procurement of materials, parts, components, and services. It provides general requirements for: the Inspection system plan, document controls, handling, and packaging and storage. Detailed requirements are provided for the Inspection systems. Cost Drivers (1B & 1C): a. Quality Program requires: o Complex multi-levels MRB activity o Costly GFP o Process Doc. Review o Sampling plans. b. Inspection Program requires: o Multi-tier inspection o OC Curves, tight AQLs o Elaborate Inspection training & certification o Complex check & balance system o Formal reporting system, many document levels
NHB 5300.4(3A)	(Soldering) Requirements for soldered electrical connections.	Defines: Requirements pertinent to the training and certification of personnel; facilities & equipment, materials, processes & procedures, and other program-type criteria considered essential to assure high quality soldered electrical connections. Also states objective criteria for acceptance/rejection of soldered connections, by use of illustrated examples as guidelines for visual inspection. Relies largely on contractor documentation & control in accordance with the cited provisions of the HDBK.

FIG. 1-a TWENTY COST-DRIVING SPECIFICATIONS (Sheet 1 of 5)

NASA/MIL #	SUBJECT	SYNOPSIS
NHB 5300.4(3A)	Continued....	Cost Drivers: Requires: o On-going training program o Does not apply to printed circuit boards except at terminals, so they require another separate inspection process to requirements of another document o Is invoked routinely on a frequent basis whether applicable or not.
NHB 6000.1(1A)	Packaging Requirements for Packaging, Handling and Transportation for Aeronautical & Space Systems, Equipment & Associated Components	This publication sets forth the general requirements for preservation, packaging, packing, marking, handling, transportation, and related data & documentation pertaining to all NASA procured software and hardware items. It provides general guidelines, but does not supersede detailed specifications or procedures which are compatible with the concept described therein. Implementation: Through Program Directives, contract statement, SOW or CEI. Cost Drivers: Within the framework of the document there is wide latitude for the specification of over-elaborate requirements, which drive costs upward.
MSFC PROC 151A MSFC-SPEC-164A	Contamination Control and Environmental protection of Space Launch Vehicles, Spacecraft, Experiments, and associated equipment procedures for: Directs Component Cleanliness as per 151A call outs	Defines: The requirements for, and verification of control of contamination and environmental protection of critical space vehicle systems, including fuel, pneumatic and oxygen systems of spacecraft and experiments from component level cleaning through launch operations. Implementation: Contract statement, SOW, or CEI. Cost Drivers: The procedure is invoked routinely, often when not needed. o Calls out more cleaning than is necessary o Calls out complex cleaning operations for simple hardware
MSFC-STD-246A	Environmental Control Areas. Design & Operational Criteria of controlled Environment areas	This is an adjunct to FED-STD-209A, which is also invoked routinely. The combination of documents contains complete instructions for setting up clean rooms from 100-100,000 classes. Also contained are rules & regulations for operating personnel as well as the rooms specifications. Implementation: Contract Statement or SOW. Cross referenced to the NHB 5300.4 series. Cost Drivers: Experience has shown that NASA calls out a higher class of room than is required, and imposes cleanliness requirements for the environment which are unnecessarily stringent.

FIG. 1-b TWENTY COST-DRIVING SPECIFICATIONS (Sheet 2)

NASA/MIL #	SUBJECT	SYNOPSIS
MIL-STD-883	Test Methods	Defines & Specifies: 20 specific test methods for high-reliability piece parts, ranging from method 1005D which treats the determination of operating life to 2012 which specifies the methods and dosage levels for X Ray inspection. This document governs the entire conduct of a HI-Rel parts program for IC and semiconductor devices as well as LST/MSI circuitry. Implementation: Contract statement, SOW. Requires Applications plan as CEI, also must be cross referenced with the NHB 5300.4(1A) reliability program, and the data from this std. form part of the reliability demonstration plan when such is specified. Cost Drivers: Low parts yield after all tests are completed, often only 6-8% o Reliability parts failure rate o Reliability Demonstration to high confidence level o Very costly test equipment o 100% parts screening and burn-in
MM 8040.12 NPC 500.1	MSFC Contractor Configuration Management	Defines: Specific methods required by MSFC which, when used by contractors afford effective control of hardware configuration. Includes elaborate traceability procedures, batch control, manufacturing controls etc. Implementation: Contract Statement, SOW, Plan is usually a CEI. Cost Drivers: There are 5 different configuration management documents in use at NASA, and in some points they contradict one another. o Whichever document is used seems to be at the discretion of the program office. o Waivers and deviations are permitted by formal request/approval. o Configuration control is imposed routinely whether or not it is necessary to control the hardware.
MIL-STD-100A MIL-D-1000	Engineering Drawing Practice	These two documents are applied in conjunction with each other. The STD calls out procedures and formats governing how the drawings should be produced. MIL-D-1000 calls out how many and what type of drawings should be produced, sufficient only for the job. There are 3 forms associated with this spec. Forms 1,2,3. Forms 1&2 are formal regimens with rigid requirements to be followed. Form 3 allows contractors to use their own system essentially, and is much less costly to implement. Forms 1&2 interface, reference, and apply 35 other documents when used. Form 3 does not. Cost Drivers: Cost drivers have been treated elsewhere in this study report (para. 4.4.9).

FIG. 1-c TWENTY COST-DRIVING SPECIFICATIONS (Sheet 3)

NASA/MIL #	SUBJECT	SYNOPSIS
MIL-STD-461A MIL-STD-462	EMC-Requirements for EMC-Measurement of	These two documents are used in conjunction with each other. Respectively they define: The requirements & test limits for measurement and determination of Electro Magnetic Interference characteristics (emission & susceptibility) of electronic, electrical, and electromechanical equipment. The detailed techniques to be used for measurement and determination of EMI characteristics. Implementation (both): SOW, CEI, or Equipment Spec. Cost Drivers: o Additional Test Equipment costs o Additional Test Program Costs o Additional Design Costs to minimize EMI o Additional cabling routing and bonding costs o Additional Facility Costs if magnetic cleanliness is required, as well as additional material and device costs. Standards are frequently invoked routinely where it is suspected that EMI MAY be a problem. Need for invocation should be determined by early Design Review
MIL-E-6051D(1)	Electromagnetic Compatibility Requirements	Often invocation of MIL-E-6051D(1) is sufficient as this sets forth general Electromagnetic Compatibility requirements. These can be met often without the 461A, 462 invocation.
MIL-STD-499	Systems Engrg. Management	Defines: Requirements for the planning, execution and management of a fully integrated system engineering effort. The elements of a management plan are defined. The scope and elements of a system engineering effort are defined and illustrated, showing the kinds of analyses and reviews necessary to a fully integrated effort, and the means of assuring contractual compliance. This document was developed by USAF Systems Command on the basis of experience with the use of the AFSC series of manuals on systems engineering, and is a replacement for the 375-5 systems engineering management procedures. MIL-STD-499 is intended to set forth all functions needed to plan, organize, and operate a systems engineering effort, FOR TRIAL PURPOSES... The intention is that the document is a guide, and would be applicable to any contract leading from concept formulation thru hardware design & development. Application to NASA programs is limited by the orientation to DoD methods of operation, and DoD and NASA methods, while similar in concept, differ in detail. Application is limited even on DoD programs by Notice 1 indicating that MIL-STD-499 is for trial purposes only. The document is not fully developed, and will be amplified further by DoD.

FIG. 1-d TWENTY COST-DRIVING SPECIFICATIONS (Sheet 4)

NASA/MIL #	SUBJECT	SYNOPSIS
MIL-STD-499	Continued....	Implementation: Through SOW. Note: Despite the trial nature of this std., as cited above, it is invoked routinely with no attention directed to Notice 1. The CIRL accompanying contracts which call out this standard, call for the full documentation complement that the standard recommends. Cost Drivers: Implementation of this STD requires: o Generation of full WBS by Task, Manning, and task segments. o RAS (rqmts. analysis sheets) must be made for each WBS item to 7th level o PERT or other tracking techniques are required. o Cost reporting by NHB 9501.2, for both contractors and NASA centers o Full Change control, configuration control with flow diagrams, and numerical tracking are called out. o Monthly, qtly, semi-annual, & annual progress reports with financial status are required, as well as periodic program audits. Estimated Cost Impact: Where this STD is implemented, costs of documentation and general program control increase by 30-40%.
MIL-STD-810B	Environmental Test Methods	This military standard is a compilation of standard test methods for determining the resistance of equipment & materials to natural & induced environments. Test methods cover such areas as altitude, high or low temperature, rain, dust, shock, vibration, and various combinations of conditions. Methods & base conditions for each test are specified. Each method lists details which must be specified in the equipment specification. Implementation: Contract, SOW or CEI. Cost Drivers: o Some of the standard tests specified are costly in terms of time and equipment to implement; i.e., thermal vacuum test at the vehicle level. Frequently full vehicle tests although called out are unnecessary o This STD causes specification proliferation, in terms of the other specs it calls out. Examples are: MIL-STD-202D, Test Methods for Electronic and Electrical-piece parts, MSFC-SPEC-101B Flammability, MSFC-STD-366 Penetrant Inspection method. MSFC-SPEC-259A Radiographic Inspection methods, etc. The document should be called out with the qualifier - "To the extent applicable" rather than routinely, or applied with a list of exceptions.
MIL-I-8500	Interchangeability Requirements	Defines: Interchangeability of parts and components. Cost Drivers: Often applied to programs where very small quantity of vehicles does not require detail of interchangeability.

FIG. 1-e TWENTY COST-DRIVING SPECIFICATIONS (Sheet 5)

during the contract negotiation process.

(2) Cost savings estimated to accrue as outcomes of modifying the 10 specifications studied represent only reductions in man-hours expended during the course of the programs studied. No materials, or hardware cost savings have been considered.

(3) Changes proposed for the 10 specifications are those which have been considered to provide a Mandatory Minimum set of requirements.

Program Selection: The two programs selected for the application of the low cost versions of the specifications are:

(1) Mariner Venus Mercury 1973 (MVM-73. JPL)(Contr. Boeing Corp)

(2) Atmospheric Explorer (GSFC)(Contr. RCA Corp Astro-Electronics Divn.)

Approach: The approach was to identify the percentage of total program costs attributable to each of the 10 cost driving specifications, for each program selected. This process was then iterated, but the assumption was made that each cost driving specification had been modified to a mandatory-minimum version. The costs of applying such a specification were estimated, again expressed as percentages of total program costs. Two summations were then compiled of actual costs, and estimated costs. The difference between these two summations represents to potential cost savings realizable for similar space programs, should specifications be restructured/modified with mandatory minimum costs as a governing criterion. The results of this exercise, together with the cost modifying changes recommended for application to the specifications are listed as depicted in Figure 2, Page 8

Limitations: Neither of the programs chosen invokes the specifications selected in their actual documented form. Both MVM-73, and AE have their own program specs written and imposed. The NASA centers (JPL, and GSFC) wrote the program specific ations based upon the 10 selected examples. Study of each specification versus the applicable portions of the center-prepared program documents revealed that in both cases, all the major cost-drivers were included. Neither the Pioneer-Venus, nor the Nimbus G program was selected for study, as both of these had less visibility into the cost data. In the case of the HEOS program, this is on-going, and definitive cost data are not available. The P71-2 program is not a NASA program, and thus does not invoke the same set of specifications; i.e. MIL-Q-9858A is used for the Quality Assurance Program regulation and control functions. In the light of these limitations, the exercise should not be considered as highly definitive, but rather as cost savings trends indicative.

COST-DRIVING SPECIFICATION INVOKED/APPLIED	MVM-73 COSTS REPORT'D	MVM-73 SAVINGS EST'D.	ATMOS EXPL'R COSTS REPORT'D	ATMOS EXPL'R SAVINGS EST'D	ALL VALUES LISTED ARE IN PERCENT TPC* — MAJOR COST REDUCING CHANGE APPLIED (ASSUMED)
NHB 5300.4(1A) Rel.	1.2	33% ⚠ / 0.8 ⚠2	1.3	38% / 0.8	Eliminate Parts Population Prediction. Use dynamic simulation. Eliminate Reliability Demonstration.
NHB 5300.4(1B) Qual	2.5	52% / 1.2	2.2	55% / 1.0	Delete Formal MRB Rqmt. Substitute informal MRB. Simplify Mgmt System. Reduce Reporting. Delete O.C.Curves. Simplify Inspection Instructions.
NHB 5300.4(1C) Insp	3.8	47% / 2.0	3.1	35% / 2.0	Inspect at Highest Possible Level. Use Double Sampling. Minimize Insp'n points in process.
NHB 5300.4(3A)Solder	1.4	46% / 0.75	2.1	60% / 0.8	Eliminate NASA certif'n for contractor solderers & inspectors. Approve process/training only. Update spec to include latest illustrations.
NHB 6000.1(1A) Pkg'g	0.15	33% / 0.1	0.2	25% / 0.15	Eliminate this General Specification. Detail Rqmts in S.O.W. per mandatory minimum.
MIL-STD-883 Test Methods	7.9	16% / 6.6	7.3	16% / 6.1	Limit Life Testing. Limit Rqmts for XRay Tests. Limit Test Repetitions. Specify Mimima not Max'a.
NPC.500.1 Config'n Mgmt.	0.35	43% / 0.2	0.8	25% / 0.6	Eliminate Batch Traceability. Elim. Mat'l Certs. Simplify numbering & Codes. Apply only for >3 S/C
MIL-STD-810B Envir'l Test.	3.2	56% / 1.4	3.9	62% / 1.5	Eliminate Thermal Vac at syst level. Apply at box lvl.Minimize Test Repetitions. Limit duration
MIL-I-8500 Interch'ly	0.2	50% / 0.1	0.25	40% / 0.15	Limit to Programs with several S/C. Std'ze parts & components. Use Std Designs as possible.
MIL-D-1000 Eng Dwgs & Lists	6.8	40% / 4.08	6.60	40% / 3.96	Reduce Form call out frm Form 2 to Form 3. Limit No. of Copies. Simplify QA & Insp Rqmts
Spec Contrib'n to Program Costs	27.50	37% / 17.23	27.75	38% / 17.11	⚠ Percent Savings due to Changes
TPC Potential Svgs. ⚠	10.3%	$3.9M	10.64	$2.34M	⚠2 New, Reduced Percentage of TPC.

* TPC = Total Program Costs

Fig.2. Affect on Program Costs of Specification Changes

Cost Estimation Method: Wherever possible, dollar values as reported by the two programs were used as the bases against which to estimate savings potentially available if specifcations were changed as tabularized in Figure 2. In many cases the dollar expenditures reported did not detail the tasks performed for such amounts. For instance, the cost value shown for MVM-73 for Quality Assurance did not break out the Quality Engineering tasks separately from the Inspection tasks. In this case, the assumption was made that Inspection averages approx 60% of the overall Quality Assurance expense to a program. This is an LMSC factor, which experience has shown applies fairly well to most aerospace contractors. Within the Quality Engineering task the work does not vary too much in terms of specific task, program to program, or contractor to contractor. The assumption was made that the usual tasks were performed such as Trouble & Failure Reporting, MRB activity (Material Review Board) Preparation of Inspection Instructions, Purchase Order Review, etc. etc. Similarly for the Inspection routines and associated tasks, the assumption was made on the basis of what LMSC would have done had the contract been performed by the company, as well as a count of the inspectable hardware items. LMSC costing factors are used to estimate dollar contribution of manhours per task, thus if a task is deleted, the gross manhours estimated for the cost of that task is reduced accordingly, and the reduced amount is converted to program dollars. A new, reduced percentage of total program costs is then computed.

Highlights and Conclusions: Several interesting points emerge from this exercise:

(1) In the initial LCPP study LMSC estimated that specifcations could drive costs of a program over a range of 25-40 %TPC. It would appear that in the case of MVM-73, and Atmosphere Explorer programs that both exhibit a specifications cost impact within this range. (ref Fig.2)

(2) Accompanying the estimate cited in (1) another estimate was made that use of cost effective, mandatory minimum specifications could afford a reduction in specification impact ranging from 10-16 %TPC. Again, this estimate would appear to be valid for both programs considered. (ref Fig.2)

(3) Although all 10 specifications listed and examined are potential cost drivers, dependent upon how invoked and interpreted, the major cost driving specs are those controlling Product Assurance activity within the programs, and those controlling Test Activity.

(4) Product Assurance Activity accounts for 8.9 %TPC on the MVM-73 Program, and 8.7% on the AE Program. While these values are average for space programs of this type, they can be reduced appreciably by use of specs whose

requirements are based upon mandatory minimum approaches. (Fig.2)

(5) In the previous LCPP program LMSC expressed the opinion that the major cost contributors to programs, other than the basic design engineering, system engineering, and manufacturing functions were Test Operations, & Product Assurance Operations. Examination of these two areas for MVM-73 and AE programs appear to support this contention. It is in these two areas that the greatest cost impact of specifications is also realized.

(6) Both the MVM-73 Program, and the AE Program are considered within the aerospace industry to be Low Cost Programs, whose specifications are definitive and rigorous. Yet significant cost benefits could accrue in similar future programs, if the major cost driving specifications imposed are revised to a mandatory minimum condition.

Conclusion: The specification library in use by NASA and the DoD afforded an effective system of checks and balances during the decade of "Success At Any Price". Such a system of checks and balances is too costly presently, and will be even more costly in the immediate future, when the "More Space Program for a Dollar Spent" aphorism is paramount. A new library of specifications based upon what is the least that will do the job, is needed urgently, and is fast becoming overdue.

Lockheed Missiles & Space Company

ENGINEERING MEMORANDUM

TITLE: SPECIFICATION COMMONALITY FOR SIX (6) SELECTED NASA SPACE PROGRAMS.	EM NO: LCPP-4 REF: DATE: January 16.1975
AUTHORS: H K Burbridge	APPROVAL: ENGINEERING SYSTEM ENGRG

Introduction: The NASA Low Cost Systems Office imposed this task as an attempt to determine the degree to which programs undertaken by the various NASA centers impose the same specifications. A representative cross section of NASA space vehicle programs was supplied for the study, these being selected by the LCSO. The programs were 5 in number from NASA centers with a USAF program contracted to LMSC included to serve as a check point for commonalities and differences DoD versus NASA. The programs studied were as follows:

PROGRAM	CENTER	CONTRACTOR.
NIMBUS G	GSFC	GENERAL ELECTRIC COMPANY.
ATMOSPHERE EXPLORER	GSFC	RCA CORPORATION.
HEAO A/C	MSFC	THOMPSON-RAMO-WOOLDRIDGE CORP.
PIONEER-VENUS	ARC	HUGHES AIRCRAFT CORP.
MVM-73	JPL	BOEING CORPORATION
P71-2	USAF	LOCKHEED MISSILES & SPACE COMPANY

Task Categories & Definitions: To better scope the task specifications were segregated into several categories. This approach has the advantage of highlighting similarities existing among specifications, but has also the marked disadvantage that many specifications must be classified in more than one category. The categories chosen may be listed as follows, and dual category examples are also given:

- o Materials Specifications......... Tells what to use
- o Process Specifications........... Tells How to use, how to make it.
- o Requirements Specifications...... Customer (NASA center) tells contractor "Thou Shalt"

- o Performance Specifications....... NASA tells contractor hardware at all levels shall perform/be operated within given parametric ranges & limits.
- o Assurance Specifications......... Tell HOW the product is to be tested.
  Tell How to conduct test
  Tell the STANDARD product must meet, over what period of time.
  Tell the DEGREE of proof NASA requires.

As has been stated, many of the specifications cross category lines, and the task of assessment and relegation of a specification to a clear cut category is at best one of engineering judgement, at worst almost impossible. Some examples are:

- o MIL-C-17D...RF Coaxial Cables. Gives requirements, but also tells how to test, & calls out material.
- o NHB 5300.4(3A) Soldering. Tells how to solder, gives requirements, gives tests & examinations to assure requirements are met.
- o MIL-HDBK-17 Plastics for Flight Vehicles: Tells what to use, how to use it, how to test, to what performance requirements, in what manner.

To the degree possible, the specifications studied during the course of this task were grouped by the most applicable single category.

Task Approach: The approach taken was to construct a matrix of specifications for the 6 programs selected. This matrix, which forms Figure 1 attached to this E.M. does not include, except by count, documents which may be classified as performance specifications. There are two reasons for not detailing these specifications:

(1) There is little relationship, program-to-program among these specifications, which are, by nature, program peculiar.

(2) The sheer quantity of such specifications would make the matrix too unwieldy to handle, and impair visibility for the other specification categories treated.

Program Practice Identifiable from the Matrix: The matrix indicates clearly that there is very little uniformity of procedure NASA center, to NASA center, in the generation, preparation, handling, and imposition of specifications in any category. Several practices are identifiable however:

(1) 3 centers, GSFC, ARC, and JPL, write, and issue materials and process specifications as program peculiar documents, making no use of existing documents in those categories. Occasionally these latter documents are used as models.

(2) All centers, and the USAF, without exception issue highly detailed program peculiar performance specifications at all hardware/software levels within a program. This practices is repeated for every program.

(3) If a given center believes such are necessary it will prepare and issue center peculiar/program peculiar assurance specifications, despite the fact that adequate NASA-wide examples of these documents exist.

(4) At least two centers, ARC and JPL, write an all-encompassing program document in which all specifications, in all categories are amalgamated into a polyglot "amorphous mass". JPL has implemented this practice on several programs in addition to the MVM-73; e.g. MM-69 and others

of that on-going series.

(5) While the practice is not identifiable from the matrix, the HEAO program from MSFC has caused the program contractor to write the hardware performance specifications, MSFC reviewing and approving only.

Cost Implications from the Matrix: The degree to which program costs have been driven by the practices listed is difficult to assess with accuracy. There are trends however, and inferences which can be made. Tabulated below are what are termed Assurance Costs for 8 programs, where Assurance is defined to mean activity undertaken by programs to assure that reliability, maintainability, and quality requirements have been met:

Program	Contractor/Center	Assurance Costs %TPC.
MVM-73	Boeing/JPL	6.1
AE	RCA/GSFC	3.1
Pio.Venus	HAC/ARC	5.5 (est. prog current)
Nimbus G	GEC/GSFC	6.2
HEAO	TRW/MSFC	6.0 (est. prog current)
P71-2	LMSC/USAF	5.1
OSO-I	HAC/GSFC	5.6
ATS-F	Fairchild/GSFC LMSC Flex-Rib antenna.	8.4

The two last programs shown in the tabulation have been included as HEAO and Pioneer Venus are on-going current programs whose cost data are not available to LMSC, and whose cost percentages are estimates only based on discussions with ARC, MSFC personnel concerned with the assurance disciplines. These estimates may not be too realistic when the programs comes to completion.

An appreciable difference in percentage of total program costs is apparent from a review of the listings. The programs,with the exception of the Atmosphere Explorer, average about 6% TPC,whereas the AE reports only approximately half that percentage. The obvious question of what was done differently on the AE program may be answered as follows:

- o All the programs listed, with the exception of Nimbus G, and P71-2 performed the assurance functions prescribed in NHB 5300.4(1B) (ref: Matrix)
- o P71-2 was responsive to MIL-Q-9858A (USAF imposed) which is in all respects equivalent to NHB 5300.4(1B).
- o Nimbus G was controlled in the assurance disciplines by GSFC-430-311 Rev.A. which is a combination specification covering Reliability, Quality Assurance, and Configuration Management. As such it is equivalent in effort expended to NHB 5300.4(1A) Reliability, NHB 5300.4(1B) Quality Assurance, and NPC 500.1 Configuration Management.
- o AE, in a major departure from the norm,invoked the NHB 5300.4 series by intent,and as a reference and guide only. The program required the contractor, RCA, to prepare and implement an assurance plan which was "lean and mean". This was done. Significant by absence were such items as reliability life assessment testing, reliability demonstration, elaborate configuration management plans, formal material review board activity, and most of the required documentation usual with assurance program plans.

Outcomes of this approach were:

(a) an overall cost reduction for the assurance program

(b) No loss of quality or mission success

(c) A significant reduction in documentation to be generated and stored.

(d) A tightly knit team of center and contractor personnel,

cost conscious, and program success-motivated.

None of the essential functions within the product assurance discipline was sacrificed, and the operating plan was implemented with a minimum of lost time, and the fewest personnel engaged at the customer/contractor interface.

Other Trends: Reference to the Specifications Matrix shows clearly that each NASA center tends to pursue its own course when selecting specifications applicable to a program. For instance MSFC, in implementing the HEAO program with TRW as contractor has issued an extremely complete list of program specifications in the form of an Applicable Documents List HEAO Spacecraft Phase C/D... HDM-4222-1 dated Feb 7/1974. This document contains not only a large number of center generated specifications of the materials and processes type, but also contains Military and Federal Specifications, Handbooks and Standards. This document is 44 pages in length, plus 8 pages of general preamble. In addition another document issued Jan 17/74 titled Contract Items Specification for HEAO-B Observatory System...72M10067, re-enumerates all the specifications of the February document, and furnishes a comprehensive and exhaustive set of performance criteria, against which TRW has generated detailed specification documents for MSFC approval. It is difficult to accept this practice as cost effective.

o MVM-73 has achieved wide acclaim throughout the aerospace industry as a low cost, on target, on time program. Despite 35 in-flight anomalies (none of which had any major, or long lasting affect upon the successful outcome of the deep space mission),the Boeing Corp was able to earn a total fee of over 14% for its efforts on this program. Two thirds of this fee was for cost effective performance within program objectives, but while this award was doubtless merited, the agency JPL, might have saved even more program costs in the area of specifications, by instituting a different practice. JPL wrote a highly detailed, fully comprehensive program-controlling master specification. This document, titled MVM-73 Space Craft Design Criteria

first issued December 11/1970 incorporated many of the "How To" types of specifcation, as well as calling out materials and processes. Very few MIL SPECs/STDs were called out, and very few NASA specifications either. The JPL specified requirements were instead incorporated in a document titled Spacecraft System Requirements Document 615-12 Contract Exhibit III. Further amplification of the tasks to be carried out by the contractor were issued as Exhibit IV Part 2. Work Units. In this document, all tasks required were numerically coded against an elaborate WBS, with JPL controlling specifications imposed as necessary. In short, the program had its own specification hierarchy. This approach appears to have been satisfactory in not only the case of MVM-73 but also in the case of several other program with JPL as the program center and Boeing Corp as the contractor. The program documentation list includes no less than 36 separate implementation plans, with attendant specifications controlling performance of hardware and software. While it is difficult to argue with program success, it is also difficult to imagine that a more standardized approach to program specification would not be possible and cost effective.

Conclusions and Recommendations: Several conclusions can be drawn from a review of the matrix. These are listed as follows:

(1) Very little commonality exists in specification approaches and practices among the NASA field centers.

(2) Centers tend to preserve an autonomy which is neither cost-effective nor indicative of any standard NASA practice or programmatic approach.

(3) In E.Ms #3 &#4 in this series on specification practices the cost driving aspects of the assurance disciplines have been explored. In the case of the AE program a low cost approach was taken to these disciplines by implementation of a low cost program plan.

(4) All centers tend toward over-specification and over-elaboration doubtless as a consequence of the long-prevalent "Success at any Price" philosophy in vogue at NASA.

(5) The non compliance with any standard approach to specifications evidenced at NASA centers applies equally to DoD, as indicated by the P71-2 program included in this E.M. for comparison. Levels of cost, in the assurance disciplines, and in the number of program peculiar documents required by a contract appear to be similar, NASA vs USAF.

Recommendations: It would appear desirable for several changes to be made in NASA specification practices. These would include, but not necessarily be limited to the following:

- A standard set of specifications should be prepared for use by all NASA centers engaged in space programs. (This excludes performance specifications which will vary, but even these could have a standard format.)
- NASA should cease to issue "How To" type specifications, aerospace contractors are qualified to employ their own methods. Sensible performance parameters, and finite "end-results expected," would be preferable.
- In the assurance disciplines, the NHB 5300.4 series stands in need of revision. Plans for these disciplines based on mandatory minima for programs, perhaps modelled along the lines of those used for Atmosphere Explorer would suffice as revisions. Additional weight to this recommendation is lent by the current DoD activity to materially revise MIL-Q-9858A, a direct equivalent of the NASA NHB 5300.4(1B). Contractors no longer can be responsive to MIL-Q-9858A at a price acceptable to DoD.
- Specifications released to the aerospace industry are required to be NASA & Tri-Service (NASA/DoD joint directive May 1964). Presently

this is not the case. Most NASA specifications issued and invoked on contracts are "Center Peculiar", and are not co-ordinated even center to center.

- A central co-ordinating activity should be set up for the generation, control, and release of specifications. The overall objective of this activity/office should be to inject into the specification process the maximum amount of standardization. Cost effectiveness of a specification should be considered before its release, and the office should be authorized by NASA management, at appropriate levels, to co-ordinate all specification activities with a similar DoD office, reported to be in existence by June 1975.

Note: JPL has been considered throughout as though it were a NASA agency. Of course, this is for convenience only, as JPL behaves in contractual matters very much as do the other NASA Field Centers.

SPECIFICATION	CENTER/CONTRACTOR & PROGRAM					
	GSFC/GEC NIMBUS G	GSFC/RCA ATMOS. EXPLR	MSFC/TRW HEAO A/C	ARC/HAC PIONEER-VENUS	JPL/BOEING MVM-73	USAF/LMSC P71-2
Quantity Prog Pec Performance Specs	48	7	Prog Pec Spec List 200+	Prog Pec Spec	Specs in 2 Prog Docmts	By hdwr 104
RQMTS SPECS						
FED-STD-209A (contam control)	-	-	X	-	X	X
MIL-STD-100A (Dwg Control)	-	-	X	-	X	-
MIL-STD-143B (Spec/STDS preced)	X	-	X	-	X	X
MIL-STD-454C (Gen Rqmts Electr)	X	GSFC Equival't	X	ARC Equivalent	JPL Equiv'lt	X
MIL-STD-461A (Elecmag Intfnc)	GSFC Equiv'lt	X	X	X	JPL Equiv'lt	X
MIL-STD-490 (Pyro Control)	-	-	X	-	-	X
MIL-STD-499A (Syst Mgmt)	-	-	X	X	-	-
MIL-STD-882 -*- (Safety Rqmts)	-	-	-	-	-	X
MIL-E-5400N (airbn Electronc)	X	-	X	-	-	X
NHB 1710.1 -*- (NASA Sfty Rqmts)	X	X	X	X	X	-
NHB 5300.4(3A) (Soldering Rq)	-	X	X	X	X	-
NHB 6000.1(A) (Trans & Logist)	-	-	X	X	-	-

FIG 1. SPECIFICATION COMMONALITY MATRIX

SPECIFICATION	CENTER/CONTRACTOR & PROGRAM					
	GSFC/GEC NIMBUS G	GSFC/RCA ATMOS EXP.	MSFC/TRW HEAO A/C	ARC/HAC PIONEER-VEN	JPL/BOEING MVM-73	USAF/LMSC P71-2
MAT'LS SPECS						
MIL-HDBK-5A (Metal Mts S/C structures)	X	Included as parts of GSFC S 320-G1, Env S/C & Compts S 620-P1 for AE,C & D	X	All included under ARC - PV-1000 ARC - PV-1006	All Included in/under S/C System Rqmts 615-12/JPL 615 Exhibits III &IV Pts 1 &2	X
MIL-HDBK-17 (Plastics flt vehicles)	X		X			X
MIL-C-17D (RF Coax Cable)	X		X			X
MIL STD 1247B (Pipe, Hose, Tube A/C Miss & S/C)	X		X			X
MIL W 81044A (Cu Wire Poly-alkens insul)	X		X			X
PROCESS SPECS						
MIL-STD-129F (Marking for shipping & storage)	X	X	X	X		X
MIL-STD-130D (I.D. Marking vs property)	X	X	X	X		X
MIL-D-5480E (Eng Data Repro)	X	-	X	-		X

FIG 1. SPECIFICATION COMMONALITY MATRIX

SPECIFICATION	CENTER/CONTRACTOR & PROGRAM					
	GSFC/GEC NIMBUS-G	GSFC/RCA ATMOS EXPLR	MSFC/TRW HEAO A/C	ARC/HAC PIONEER-VENUS	JPL/BOEING MVM-73	USAF/LMSC P71-2
ASSURANCE SPECS						
MIL-HDBK-217A (Failure Rates)	-	-	-	-	-	X
MIL-STD-756A (Rel.Prediction)	-	-	-	-	-	X
MIL-STD-785A * (Rel Programs)	-	-	-	-	-	X
MIL-Q-9858A ** (Quality Prog)	-	-	-	-	-	X
NPC-200-3 (Insp'n System)	X	X	X	X	X	-
NPC-250-1 (Reliability Prog)	X (later Rel/QA S402-A)	-	-	-	-	-
NHB 5300.4(1A)* (Reliability Prog)	-	X	X	X	X	-
NHB 5300.4(1B)** (Quality Program)	Equivalent-GSFC-430-311A	X (modif)	X	X	X	-
AFWTRM-127-1 (Range Safety Assurance Rqmts)	-	-	-	-	-	X

Notes

* Equivalents -*-

** Equivalents

\- Not Imposed

X Imposed

FIG 1. SPECIFICATION COMMONALITY MATRIX

ENGINEERING MEMORANDUM

TITLE: A Plan for Establishing a Central Specification Control Office/Facility	EM NO: LCPP-5 REF: DATE: April 10/1975
AUTHORS: Henry K Burbridge	APPROVAL: ENGINEERING SYSTEM ENGRG D L Hannaford

1. Objective: The underlying objective in establishing a Central Specification Control Office (CSCO) is to effect a substantial saving in NASA Program expenditures. Such an end may be achieved through elimination of specification proliferation, duplication, ambiguities, and overall lack of regulation and control. In addition to furnishing an improved specification control system, the system may be employed to accommodate other program documentation, thus affording further savings. In other EMs in this series it has been estimated that better control of specifications and program documentation could result in savings in the following range:

Specifications Savings........ 10-16% of Program Dollars (TPC)
Documentation Savings........ 8-11% of Program Dollars (TPC)
Total Possible Savings........ 18-27% (TPC)

This EM furnishes planning for such a Control Office, to the degree necessary to demonstrate the concept, which if implemented, can afford such cost benefits. As better specifications, better control of these program regulating documents, and overall improvement in their content in terms of intelligibility, and brevity are realized; the synergistic effect will be appreciable as more and better hardware per program dollar expended. This plan is offered in two parts: Part 1 depicts the present situation, and Part 2 which treats the institution of the CSCO.

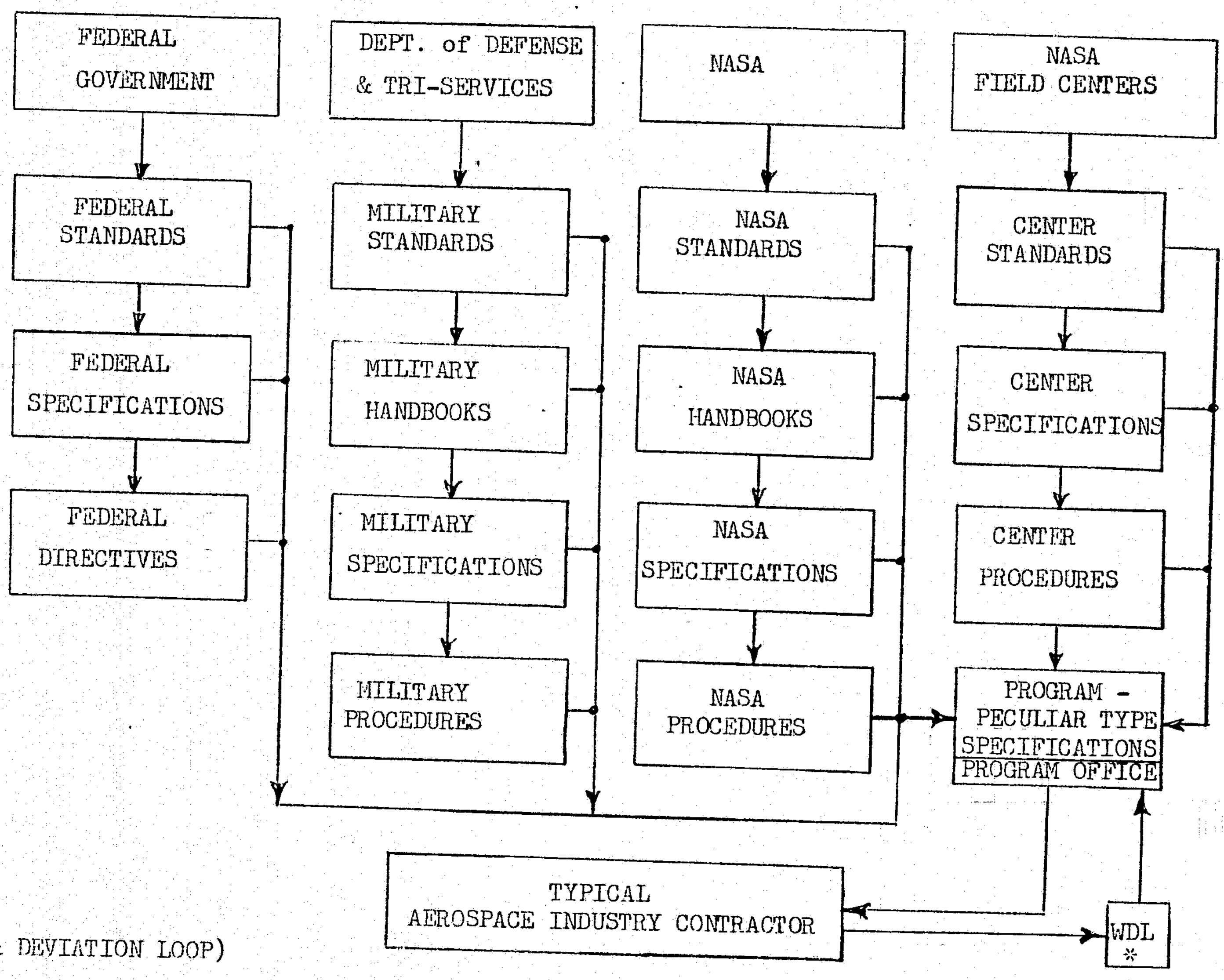
2. Part 1; The Current Situation: Specifications of a multitude of types, pertaining to every phase of development and manufacture of space hardware/sofware are available today. NASA can, and usually does, invoke a large number of these when contracting with aerospace companies. The companies are vitally concerned

with compliance with NASA terms and directives on a continuing basis, and therefore spend much effort in assuring that such compliance is as complete as possible. Costs of such activity are passed on to the Government in the course of contracted performance on the basis of: "NASA can have anything it wishes, provided due payment is forthcoming" In the case of specifations, a bewildering maze exist through which both NASA program managers, and the contractors must find a path. As with any other maze, there are many dead ends, and side avenues residual from the days when the aerospace industry was learning the space business. When these side avenues are invoked, either by inadvertence, or habitual practice, costs can only increase. Figure 2.1 illustrates the number of specification sources existing, any or all of which can be invoked by NASA at the discretion of a Program Manager or COR. For sake of clarity the many cross links are not shown, but it is notable that the only "Escape Hatch" is a small one, designated WD to denote the Waiver & Deviation loop. All avenues funnel into the NASA Center Program Office, and again for clarity, the contracts loop is omitted, as is the aspect of multiple center involvement.

3. Current Regulation & Controls: In 1964 the DoD discerned that the hierarchy of military specifcations and documents was growing at an alarming rate. A Regulating Board was formed, the NASA & Tri-Service Review Board, and vested with the authority to:

- o Review existing specs, and require updates, additions, and deletions.
- o Co-ordinate specifications release among the several Govt. Agencies
- o Furnish advice on an Ad-Hoc basis to both Govt Agencies & the aerospace industry, on improvement of the specification system.
- o Act as mediator, Govt vs industry for specification matters.
- o Fund aerospace contractors to prepare specifications under contracts.
- o Employ delegates/specialists from both Govt. and industry.

THE SPECIFICATION MAZE



*(WAIVER & DEVIATION LOOP)

The Board is comprised of a chairman, a secretary, two members from each of the armed services, two members from DoD, at least one member from each NASA field center (7 in all) plus a NASA/HQ member, and six members-at-large from the aerospace industry. These latter members are not full time participants however. They are consulted as the need arises, and act as intercessionaries, aerospace vs the Board. Unfortunately, the board has comparatively little affect upon the specification maze for this reason:

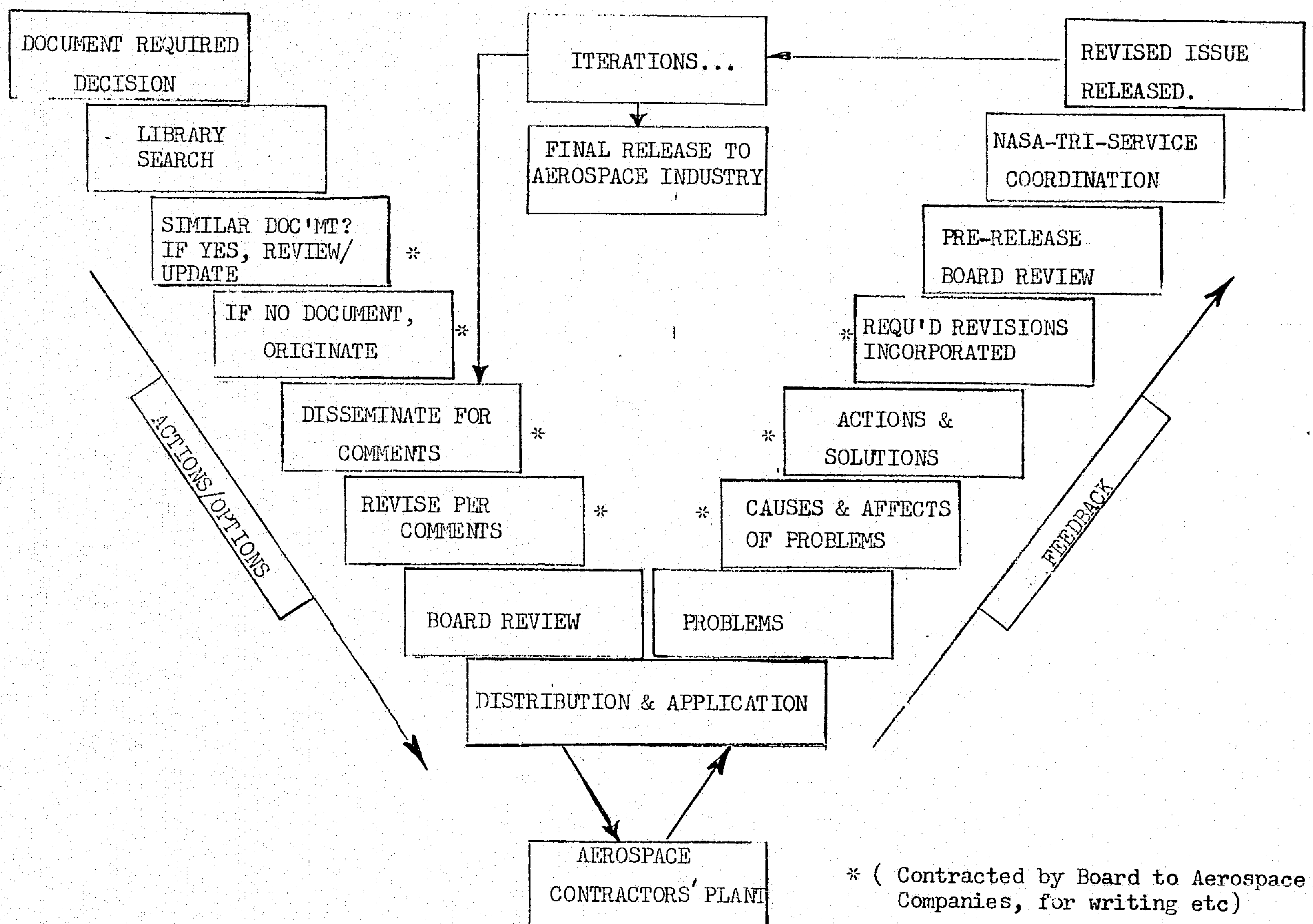
Each of the major contracting agencies, i.e. Army Navy Airforce, and each NASA center reserved the right to generate such specifications as each believed to be necessary to its own operational peculiarities. For example, a MSFC Procedure is an internally generated document, and there is no requirement for it to be co-ordinated among the other NASA centers, NASA HQ and the Review Board. The outcome is that such a document can have, and frequently does have, parallels existing in other centers than the one generating it. Each document is autonomous, subtly different (sometimes grossly different), and binding upon a contractor if invoked.

3.1 Board Operations: In a non-NASA milieu, the Board is somewhat more effective. This is due primarily to the fact that the Armed Services were largely responsible for the generation of many of the MIL prefaced documents in use today. NASA, as a late comer into the aerospace industry domain, also uses many of the MIL documents, as in NASA operations often there was no time to generate NASA peculiar documents. The converse does not hold good however, as it is very seldom that the Armed Services use a NASA generated document. Since the inception of the Board, NASA has gone its own way with respect to generation, imposition, and implementation of specifications, and there have been almost no

instances recorded when NASA adopted a specification, or other regulatory document, reviewed and released by the Board. However, the Board has released many documents to the services after review and coordination, most of which have borne the statement "NASA & Tri-Service". In almost all cases NASA has chosen to ignore this entitlement, although by definition of the Board, NASA is required to use an existing document if possible. In short, the Board, so far as NASA is concerned, is a "Toothless Tiger". A very good example of this fact is the case of MIL-STD-882 System Safety Program for Systems & Associated Equipment: Requirements for. After some 22 months of effort commencing circa Jan 1969, the specs & Stds groups of Mc Donnell-Douglas, LMSC, and Hughes Aircraft Corp, prepared, revised, and co-ordinated drafts of the STD with all services and NASA, the Board acting as intermediary. The completed document was released in October 1970, and adopted by the Armed Services, primarily USAF. NASA, claimed special safety precautions/measures had proved necessary for the manned Apollo program, and would continue to be necessary for the Skylab program. As a result NASA originated the NHB 1710.1 series dealing with Safety, although the MIL STD would have sufficed with but minor revisions/additions.

3.1.1. The Board Procedures: On the average the Board requires from 18-26 months to handle a new document, and the method of handling is shown in Figure 3.1.1 Specification Processing. As illustrated, the handling mechanism is a close-loop complex piece-wise step system, which theoretically can be entered at any step point in the chain, so that existing documents can be reviewed, updated, and re-issued. In practice the system is serial in operation; remove a link in the chain, and the entire operation is disrupted. Some "short-cuts"are possible, by means of pre-determined by-passes, such as allowing the aerospace industry to prepare and implement the spec, de-bug it, and then submit it to the Board together with recommendations to implement. With Board concurrence

SPECIFICATION PROCESSING BY THE NASA/TRI-SERVICE BOARD



* (Contracted by Board to Aerospace Companies, for writing etc)

Part 1. Figure 3.1.1.

dissemination then proceeds immediately. As is obvious by the average elapsed time, and the fact that NASA pursues its own course, the Board affords little advantage to NASA, at least in the space hardware domain. The costs of operating the Board are not inconsiderable, although no cost data are available to LMSC currently.

4. Recommendation: LMSC recommends that NASA terminate its participation in the Board, instituting instead a Central Specification Control Office as described in Part 2 of this EM.

Part 2 A Central Specification Control Office (CSCO)

2.1 General Planning: It is recommended that the Specification Control Office be located at NASA/HQ, with facilities as described herein, and with represen-tives at each NASA Field Center. The Office need not be a large organization, and most probably would not require the full-time services of more than 4-5 persons:

- A Coordinator/Supervisor. (and clerical support)
- A Cost-Cost/Worth analyst
- A Librarian
- A Senior Technical Writer

Technical services would be provided on an "As Needed" basis, and the Field Center Representatives would undertake NASA/HQ liaison, and liaison with the aerospace industry on a part-time basis, perhaps 50% of their time being employed in this manner. The functions of the CSCO are illustrated in Figure 2.1.1. Functions of the CSCO, and the aims and objectives of the CSCO are the subject of Figure 2.1.2. titled Aims and Objectives

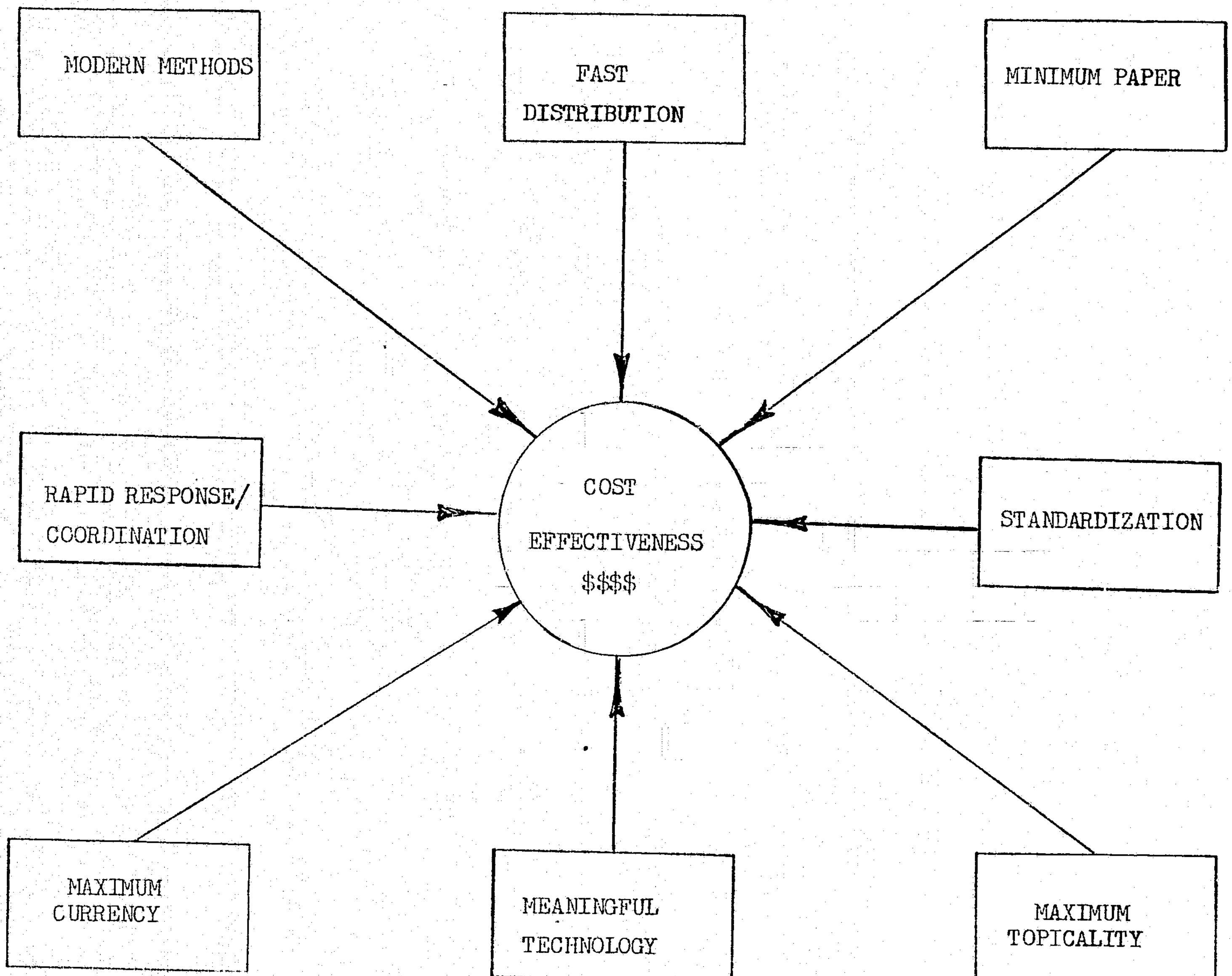
FUNCTIONS OF THE CSCO

- **NASA/HQ CENTRAL COORDINATION ACTIVITY** FT
  - Admin Support
  - **Specifications Engineering Activity** AN
    - Mat'ls & Process
    - Value Engineering
    - Aeronautical Eng
    - Mechanical Engrg
    - Electrical Engrg
    - Electronic Engrg
    - Chemical/Metall'gy
    - Manufacturing Eng
  - **Library Service Activity** FT
    - Computer Interface
    - Hi-Speed Printing
    - Microfiche/film
    - Reproduction
    - Distribution
  - **Assurance Disciplines Activity** AN
    - Reliability Eng
    - Maintainability
    - Safety Engrg
    - Quality Assurance
    - Logistics
  - **Cost/NEED Analysis Activity** AN
    - Worth Analysis
    - Effectiveness
    - Cost Liaison
    - NEED Determination
  - **Technical Writg Illustration & Editing Activity** AN
    - Standards/Specs
    - Handbooks
    - Manuals/Proc'drs
  - **Field Center & Industry Liaison Activity** PT
    - NASA Centers
    - Aerospace Industry
    - Gov't Agencies

Codes:
AN-As Needed
FT-Full Time
PT-Part Time

Part 2. Figure 2.1.1.

CENTRAL SPECIFICATION CONTROL OFFICE - AIMS, & OBJECTIVES



Part 2. Figure 2.1.2.

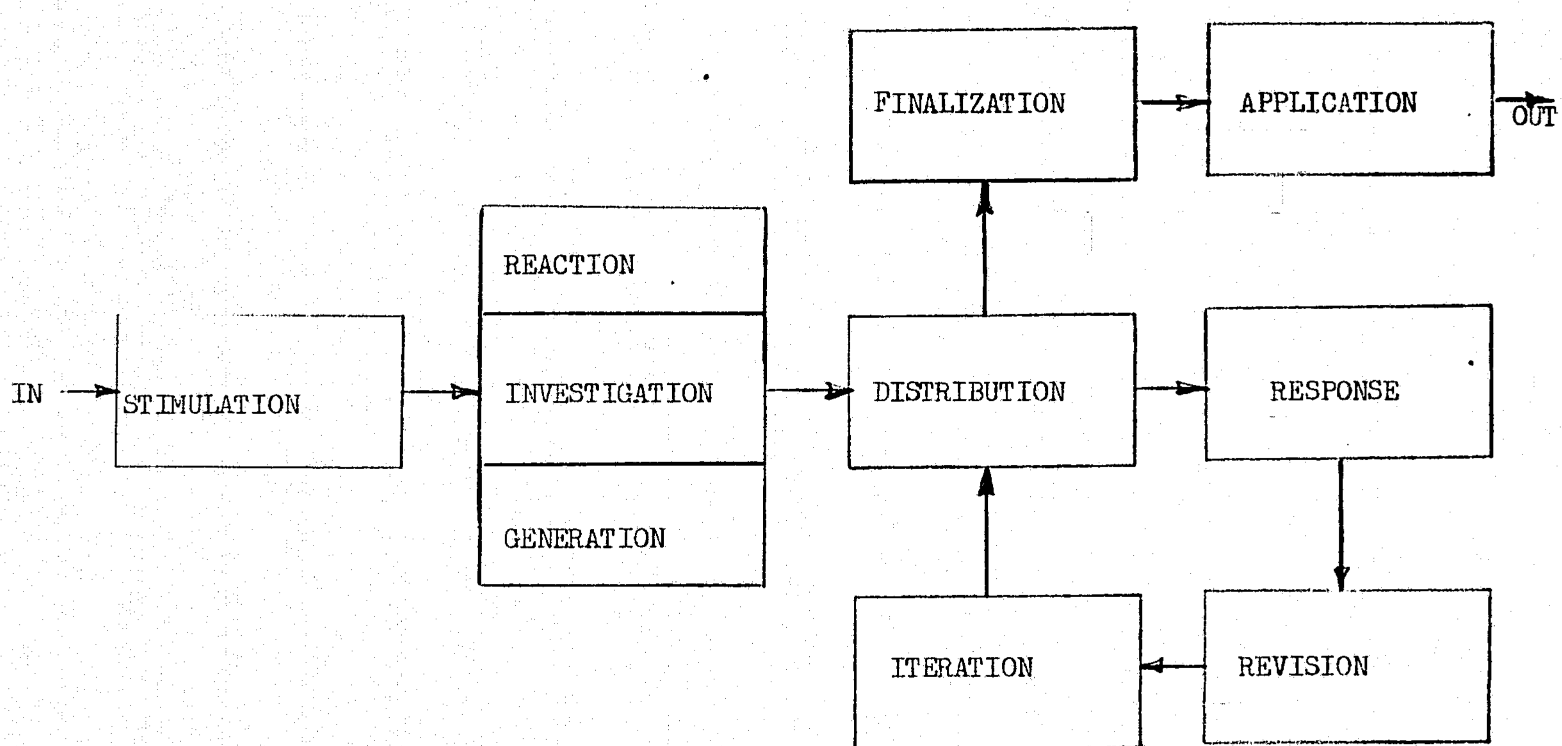
2.2 Systemic Logic: The logic of the operation is essentially extremely simple, and is depicted in Figure 2.2.1. CSCO Systemic Process. In brief, the process functions as follows:

- o Stimuli are furnished by NASA Centers and/or program offices, who cite a NEED together with a justification for such a need, and an accompanying Cost/Worth analysis.
- o Reaction causes a Specifications Library check to be made, using an high speed computer and printer to perform the Investigation. The initial Cost/Worth analysis is verified within the CSCO, and the process of either existing document updating, or new document Generation begins.
- o Distribution of the drafted copies is undertaken by the library and dates are set for:
- o Response by all addressees, whose comments and technical critique cause the preparation of:
- o Revisions This process is subject to:
- o Iteration for as many passes as are required to refine the document. As a general rule, iterations will be held to not more than 3 to minimize time-in-the-loop, and allow:
- o Final Release of the specification or other document to users.
- o Application can then begin throughout NASA and the aerospace industry

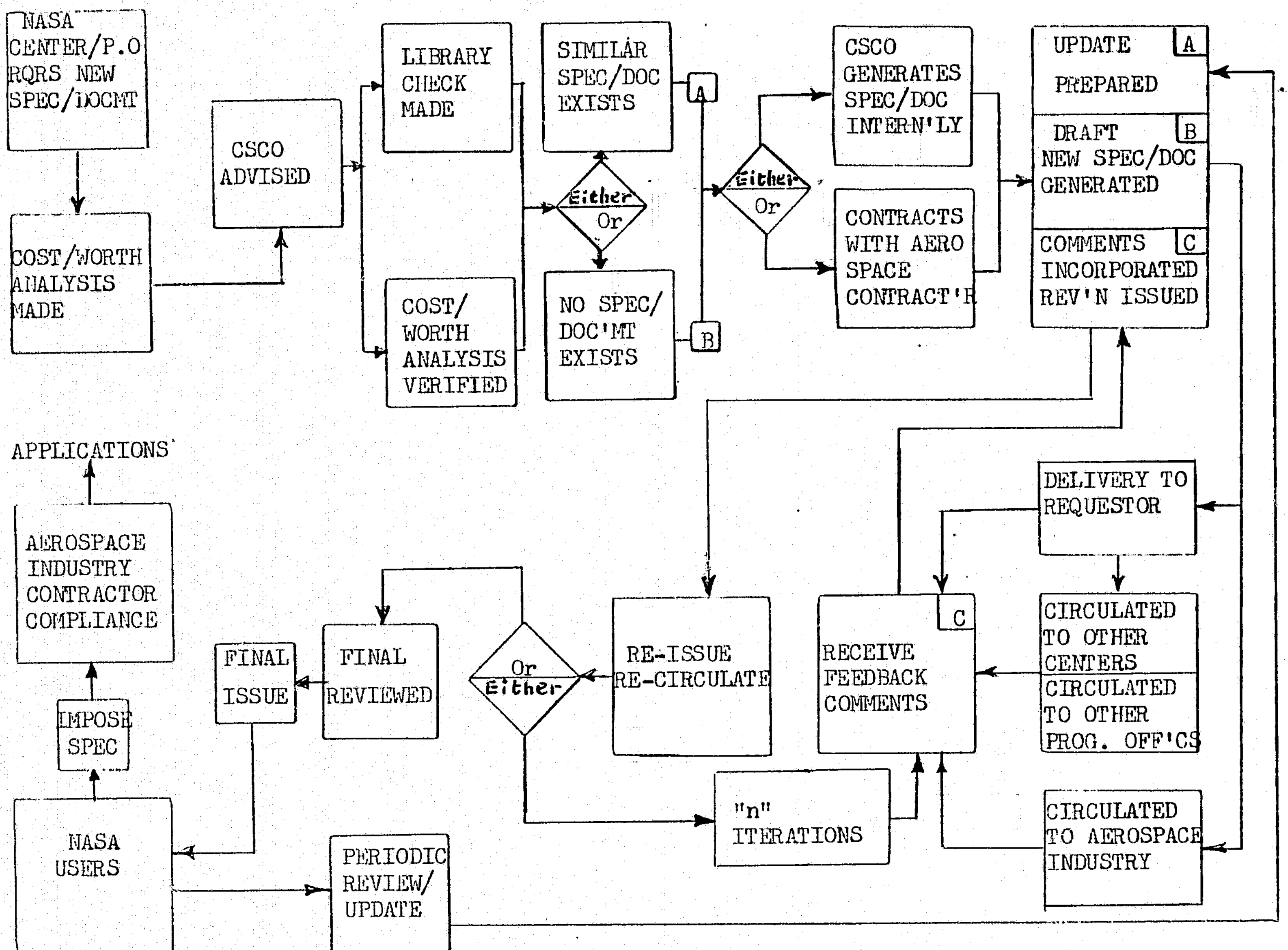
2.3 Detailed Work Flow: Based upon the foregoing logic, a detailed work-flow diagram, Figure 2.3.1. Central Specifications Control Office Work Flow, is included. This figure, which is self explanatory in terms of CSCO operations, illustrates the options, specific task functions, work processes, and release

Part 2. Figure 2.2.1

CSCO - SYSTEMIC PROCESS



CENTRAL SPECIFICATIONS CONTROL OFFICE WORK FLOW



Part 2. Figure 2.3.1.

system.

2.4. CSCO Task Priorities: Much has been written by LMSC and other aerospace companies concerning the specification proliferation, duplication, and obsolescence in the present system. In addition to these factors, all of which tend to drive program costs upward, as is shown in Figure 2.1; the present specification hierarchy is a mix of Federal, DoD, Tri-Service and NASA documents. The first task recommended for implementation by the CSCO is that of creating some order from this chaos. In particular, this task will require screening the entire aggregation of documents currently existing; removing those which are outdated, or are duplications of other documents, and recoding/cross referencing the balance with a NASA coding/numbering/titling system. The entire library, which will be stored in micro-fiche/microfilm form, should be coded and computer referenced. When the need for a paper copy arises, this can be reproduced by a combination of the Hi-Speed printer for text, and an XY plotter such as the SC 4020 for graphical data. Each Center can be equipped with a CSCO interrogation facility which, by means of leased lines would permit a Center CSCO Rep to acquire a specification copy in a rapid fashion. Either text, by hispeed printer, or art by Facs (facsimile transmission) could be available, or both, as needed.

2.5 The Center CSCO Representative: Such personnel, who would probably be assigned part-time only, would be specialists in one or more engineering discipline, of one or more of the assurance disciplines. In addition to their expertise, they would require experience in the generation of technical specifications. The problems existing currently are that most personnel do not know what specifications exist, what these cover, their state of currency, and the work, confusion, and hence costs, arising from their implementation. Such ignorance causes specifications to be imposed on contractors routinely, and whether

applicable or not. What is worse, all of the sub-tier documents are invoked automatically, by dependency. The major duty of the CSCO Rep at each Center will be to interface with aerospace contractors, other NASA Centers and Program Offices to:

- o Advise what specifications/documents will be needed
- o Advise what exists currently, and what new items will be required
- o Advise of problems arising from imposition of current specifications/documentation requests upon the aerospace industry.
- o Process requests for CSCO to produce new specifications, update current issues, and expedite response time to such requests.
- o Coordinate CSCO policies & procedures with the Center to which he is assigned.
- o Provide cost data on specification implementation, also cost targets.

3. Conclusions: An urgent need exists for NASA to undertake major revision of the specification hierarchy existing presently. This need has been highlighted in numerous studies undertaken by LMSC and other aerospace contractors over the past 5 years. While this EM can do no more than suggest the groundwork for a NASA Central Specifications & Documentation Control Office (CSDCO), it urges that NASA consider such an office to be a near-term priority. LMSC believes that considerable savings of the order cited in the opening paragraph of this EM may be achieved, merely by improvement of the specifications used to regulate program performance. Finally the office, as has been shown herein, can be used as an effective means for the control of all forms of program documentation; both NASA and contractor generated. The CSDCO can proive a means of realizing the intent of the slogan: "Less paper; more and better hardware for the NASA Program Dollar Expended."

ENGINEERING MEMORANDUM

TITLE: A LOW COST VERSION OF NHB 5300.4(1B), QUALITY PROGRAM PROVISIONS FOR S/S CONTRACTORS	EM NO: LCPP-6 REF: DATE: February 24/75
AUTHORS: H K Burbridge	APPROVAL: ENGINEERING SYSTEM ENGRG D J Hannaford

1. Introduction

NHB 5300.4(1B) Quality Program Provisions for Space System Contractors was issued in April 1969.

The document replaced NPC-200-2 dated April 1962, and was an attempt to update and streamline the quality provisions mandated by NASA for controlling the quality of spaceborne hardware. As such, the update and streamlining process was extended to include the reliability activity, the soldering activity, and the inspection activity, so that the complete NASA Handbook included most of the assurance support activities, with the exception of maintainability, safety and logistics. At present, the NHB series is structured as follows:

- o NHB 5300.4(1A) which covers reliability.
- o NHB 5300.4(1B) which covers Quality Assurance.
- o NHB 5300.4(1C) which covers Inspection.

2. Handbook Specifics

The handbook, while organized as a separate document, is structured along the lines of the DoD document MIL-Q-9858A. As such, the handbook shares not only the strengths of the DoD document but also the disadvantages. In the most general sense the paramount problem with both of the documents is not that anything is missing from them, but rather that the degree to which activity prescribed must be accomplished is not specified. Secondarily, there are several inclusions descriptive of program activities which do not properly fall within the purview of Quality control, but which appear to have been included for lack of a better place to treat them.

2.1. Organization of the Handbook

The handbook is organized into thirteen chapters as follows:

Chapter 1: Introduction.

Chapter 2: Quality Program Management & Planning

Chapter 3: Design and Development Controls

Chapter 4: Identification and Data Retrieval

Chapter 5: Procurement Controls

Chapter 6: Fabrication Controls

Chapter 7: Inspections and Tests

Chapter 8: Non Conforming Article and Material Control

Chapter 9: Metrology Controls

Chapter 10: Stamp Controls

Chapter 11: Handling, Storage, Preservation, Marking, Labelling, Packaging, Packing and Shipping.

Chapter 12: Sampling Plans, Statistical Planning and Analysis

Chapter 13: Government Property Control

Appendix A: Quality Program Cross-Reference Index

Appendix B: Glossary of Terms.

Each of these chapters is further sub-divided into several categories, most of which commence with the mandate: "The contractor shall..." What the contractor is required to do is quite clearly prescribed. How the contractor is to do it, or whay it should be done at all, is usually not stated, or if a statement IS made it is couched in vague, general terms. MIL-Q-9858A possessed similar deficiencies, to such an extent, that in an attempt to remedy them the DoD produced Handbook 50. This document purported to supply the "How" and the "Why", but in actuality provided more confusion than clarification.

3. Cost Driving Aspects of the Handbook

3.1 NASA vs The Aerospace Industry in Program Planning

The number of contractors who are capable of marshalling the resources required to bid for NASA space programs is relatively small. After almost 20 years in

designing and fabricating space vehicles, the individual contractor has amassed considerable expertise in the provision of a quality product, and the "groundrules" by which such provision is accomplished are well established. Despite this condition, NHB 5300.4(1B) requires that for each, and every program, contractors prepare, and submit for approval, a quality assurance plan. This plan is to be readily identifiable with each cited requirement (which mandates its format) , must cover all quality activity throughout the time period or phase authorized, must be updated periodically and re-submitted for approval, and must specify exactly how the contractor proposes to be responsive to the requirements of NHB 5300.4(1B). In practice, what transpires is the production of a plan of the boilerplate variety. Each contractor submits the same kind of a plan, with statements tailored to match the paragraphs of NHB 5300.4(1B), for every NASA solicitation upon which the contractor bids. Relatively speaking, apart from the cost values involved in the programs, there is no variation program to program, in any of these plans; nor is there much variation contractor to contractor. One of the requirements to be met is the provision of work-flow diagrams which show the quality audit points, and inspection points throughout the program. As may be imagined, on a large program such as the shuttle, the program plan becomes a sizable document. Program plans of this kind, which often are required to be submitted in preliminary form with the contractor's response to the NASA RFP, can run as high as $25000.00... As was stated earlier, the relatively few companies providing space hardware for NASA operate in similar fashions, each to the other. It would appear more cost effective for NASA to retain a SAMPLE plan for each contractor, and require additional program planning for space programs only if there are special problems envisioned, or novel methods to be used.

3.2 The NASA/Contractor "Paper Mill"

At the end of NHB 5300.4(1B) there is an Appendix A. Listed in this document appendage are 40 document titles, each of which is cross referenced to one or more paragraphs of the NHB 5300.4 (1B). If the provisions of any given NASA contract are strictly enforced by a contracting officer, each of the documents listed in the Appendix must be prepared, updated, and maintained for the life of that contract, and in some cases for a protracted period thereafter. Obviously, many of the documents exist from contract to contract, for example the Change Control Sysyem Document, which merely notifies NASA that a change control system is in operation and is administered in some given manner. The significance of this appendix is that per contract every one of these documents must be prepared, reproduced, and transmitted to NASA should full compliance be mandated. In actuality those required are listed in the CIRL, and this list includes most of them. It has not proved possible to estimate the expenditures per contract involved with compliance to this documents appendix, yet it is apparent that such costs may be appreciable. If the list is to be retained at all, it should be scrutinized carefully by NASA to determine which of the documents is really necessary, the criterion for document retention being what impact it has, or may have, upon the final quality of space destined hardware.

3.3 Government Property Control

Chapter 13 of NHB 5300.4(1B) deals with the control of Government Furnished Property. The responsibilities of the contractor are mandated with respect to the accountability, maintenance, shipment, periodic inspection accorded to Government Furnished Equipment. In addition, the contractor is given instructions on the handling, reporting, segregation and disposition of any GFE found to be defective.

Particularly, the contractor is instructed to proceed in accordance with Government Procedures, when confronted with unsuitable GFE. What procedures are involved are not specified in this handbook, but in fact Fed-Std-717 Control of Government Property is involved. LMSC has not been able to determine what portion of Quality Assurance funds are expended on this activity customarily, nor are there well defined records of what GFE NASA furnishes to what particular contract or program readily available. On a large program such as Apollo however, where the involvement of GFP/GFE was considerable, control measures for such property/equipment cost the program several million dollars. LMSC believes that Government Property control should not be made a part of Quality Assurance Provisions. Rather the property should be handled and processed like any other bonded inventory items. Since Government Property is usually facilities and/or large test equipment items, the responsibility of handling such, should be vested in general inventory control and accountability. Supervision of this operation should be undertaken by Program Administration rather than Quality Assurance, and the particulars of what the Government requires should be covered in the general provisions of NASA contracts.

3.4 Non Conforming Article & Material Control: The major cost driving influence in this chapter of the Quality Provisions document is the delay that can be injected into a program as an outcome of the "Built in Moment of Inertia of the Board". The Material Review process requires that an initial assessment of nonconformance be made by the quality assurance personnel of the contractor involved. The findings of these personnel must then be forward to the on-site board, whose members review the situation and make decision as to disposition of the discrepant materiel/items. In all cases where the decision involves rework/repair, or use-as-is, board recommnedations must be forwarded to the NASA contracting officer (COR) for concurrence. Frequently costly items are purchased as ones-of-a-kind for which no spare has been provided, either by buy action or fabrication. A decision to repair at the vendors' plants, or a re-work at the contractors' facilities must inevitably call for schedule slippages. Recommendations to simplify activity in material review will be treated elsewhere in this EM.

3.5 Architecting the "Empires": One of the difficulties of a document such as NHB 5300.4(1B) lies in its lack of specific direction. Many of the statements of requirements commence with the phrase, "The Contractor shall Provide...." Contractors have a vested interest in providing that which the customer requires, since failure to do so could result in an adjudication of non-compliance with customer requirements. The problems arises from the fact that many of the tasks that the contractor is directed to perform in the Quality Provisions document, are not quality tasks. Each of these cases will be treated in the detailed analysis of the provisions of the handbook which follows this description of its cost driving aspects, but one or two examples are given to illustrate the difficulties. In chapter 7 dealing with Inspections and Tests, paragraph 1B702 deals with the preparation and use of test specifications for each test to be performed. Since the paragraph is contained within the quality provisions document, contractors' quality organizations have construed such a direction to apply directly to them. The outcome has been the institution of organizational subdivisions known as "Quality Test Operations" or other similar titles. In actuality, what NASA really intended was that Design, and Systems Engineering determine and specify what test should be performed, at what levels, Test Operations personnel should specify equipment requirements, make such equipment available on-schedule, and perform the tests, with program management exercising supervisory control of the entire operation. The role of the assurnace disciplines in the test function should be only those necessary to assure that:

(a) The tests have been performed to the number, and duration of tests specified.
(b) The test criteria have been met, or not.
(c) Discrepancies are identified and handled.
(d) All test activity has been incorporated into the program permenant record.

Such procedures, when implemented would assure that costly duplications of the test function would not occur.

Similarly in Paragraph 1B603 which deals with Process Controls, such controls are intended to be specified and undertaken by Process Engineering. The only QA role should be that of assurance that this activity has been carried out, and that the processes are under control.

Again, specifics will be given in the detailed analysis of the specification, but an example of the cost driving aspects of costs occasioned by the quality document be so general as to allow arrogation of many responsbilities to the quality organization, not properly theirs; may be found in the fact that on several programs undertaken by NASA, QA costs have run as high as 43% of the manufacturing costs!

4.0. Digest of Contents, NHB 5300.4(1B): As has been listed earlier in this EM, the Quality Provisions Handbook contains thirteen chapters. For ease of understanding the provisions of the handbook, and to facilitate reading this EM without the necessity of recourse to a copy of the handbook; the following digest is provided:

4.1 Chapter 1, Introduction: This chapter, which has been assigned alpha numeric designators 1B100 thru 1B104 introduces the theme of the handbook. The chapter furnishes a general preamble, the relation of quality assurance to other contract requirments, sets forth actions and prerogatives of the government, details documents required by the quality program cross referencing these to applicable paragraphs of the handbook, and furnishes a glossary of Quality Assurance terms used. Of particular interest is the paragraph dealing with actions of the government, and its prerogatives. This informs the contractor that all aspects of the quality program he institutes are subject to governmental examination, by either the NASA, or other surveillance agency of the government appointed by NASA as its representative.

4.2. Quality Program Management and Planning: The chapter covers designators 1B200 thru 1B206treating Generalities, Organization, Training, Quality Information required, Quality Status Reporting, Quality Program Audits, and the Quality Program Plan. The thrust of the chapter is to detail to the contractor how must be managed the quality program he is required to institute. The significant paragraph is the last one, which deals with the quality plan which is to be prepared for every program. This plan is required to cover all other requirements set forth in the handbook.

4.3. Design and Development Controls: Only three subjects are covered in this chapter. 1B300 thru 1B302 set forth the quality involvement in technical documentaton, the support Quality Assurance is to furnish to Design Reviews, and the role QA is to play in change control. Each paragraph is generalized to the point where it is difficult to determine what QA really is required to provide.

4.4. Identification and Data Retrieval: The contents of this chapter are designated 1B400 thru 1B405. The subject matter covered is a General Preamble which explains the import of the chapter, Methods of Identification by Date Codes, Lot Numbers, Serial Numbers, and other methods permissible, Documentation requirements in terms of identifications, and part numbers, control of identification numbers, the provision of lists on which all items contractor, and supplier-designed, shall be identified by part and type number, and the methods of verification of parts/materials versus identification lists, versus pertinent program records.

4.5. Procurement Controls: NASA attaches considerable importance to the control of contractor procured items. This chapter contains eleven (11) sub-chapters, which detail for the contractor thru sections 1B500-1B510 inclusive, his responsibility for all purchased articles, materials, and services, Quality Assurance involvement in the selection of procurement sources, and the criteria covering such involvement, the review of supplier quality programs for adequacy and compliance with the requirements of the NHB Handbook, all of which requirements are listed in some detail, the assignment of contract quality personnel at suppliers' plants and facilities, and details of how this must be done, a statement of the intent of Government Source Inspection, which, as, and when conducted, in no way relieves the contractor of his quality responsibilities, the receiving inspection system required of the contractor, and elaboration of that theme, the receiving records required, and the manner in which they are to be kept, the system for rating suppliers in terms of the quality of their product, the requirement for post-award surveys, and the criteria for their conduct, the need for co-ordination of contractor-supplier inspections and tests, the requirement for feedback, contractor to supplier, of information on non conformances to facilitate timely corrective action, which is the final paragraph, 1B510.

4.6. Fabrication Controls: This chapter contains 5 subchapters; 1B600 thru 1B 604. These cover the controls required throughout all phases of hardware fabrication, the controls required to assure that only conforming articles and materials are released for use; such controls being inclusive of critical life articles

and items; the control of cleanliness throughout allphases of the fabrication, assembly, test, storage and shipping operations, the controls to be provided for those articles whose conformance cannot be determined by inspection alone, these being particularly oriented toward such processes as plating, chemical processes, et al., and finally the criteria for the joint selection by NASA and the contractors, of samples, and/or visual aids showing acceptable workmanship.

4.7. Inspections and Tests: There are 8 sub-sections in this chapter, numbered 1B700-1B707. They include a general statement concerning the requirement to plan and conduct an inspection and test program, the criteria against which such a program is to be planned and conducted, the requirement to use test specifications for each item to be tested and each test to be performed, and details of the contents of such specifications; the requirement for the contractor to prepare written procedures for tests and inspections to be conducted, with 13 sub-criteria listed, a statement that separate end-item inspection and test procedures shall be prepared and used together with applicable criteria for these; a considerable treatise on the methods and requirements considered mandatory for inspection and test performance, with stress on the control of Qualification Test Articles, the conduct of Requalification Testing, edicts concerning Qualification Based on Similarity, and the criteria governing inspection and test of end items. This latter sub-section is cross referenced to chapter 8 with respect to the manner of dealing with non-conformances discovered during and after test and prior to shipping, and includes requirements statements concerning re-test activity, and the preparation of End-Item Inspection and Test Reports. In addition to all of the foregoing, the contractor is required to generate Inspection and Test Records and data concerning all test activity undertaken, and finally, a list of Contractor Quality Assurance Actions to be taken before testing commences is furnished.

4.8. Non-Conforming Article and Material Control: This chapter has 7 sub-sections. These, designated 1B800 thru 1B806, cover the definition of non-conformance, documentation required of the contractor in his program to control non-conforming materials and items, the prescribed remedial and preventive action the contractor and his suppliers are expected to take, the requirement for initial reviews & dispositions to be made by contractor quality personnel, together with details thereof, a description of the Material Review Board together with its

membership, functions, and authority, a statement of requirements for Written Request For Approval by the NASA Contracting Officer to be generated whenever a contractor recommends a disposition to repair, or use items as-is, and finally, permission with NASA approval for the contractor to delegate MRB responsibility to suppliers, if the contractor so elects.

4.9. Metrology Controls:This chapter, which has 8 subsections designated from 1B900-1B907, deals with the documented system which the contractor is to use for control of the measurement processes evidential of quality performance. The subsections deal with Acceptance of all standards and measurement equipment prior to use by an inspection process, the means of evaluation to ensure the validity and compatibility of measurement standards to the hardware they are to measure, the processes by which measurements are to be made, the calibration process for the standards, together with its details of traceability, handling, storage, and transportation of the standards, their identification and labelling, calibrations and their intervals, the recall system for recalibration, and the calbration records requirements. In addition to all of the forgoing, the requirement that environmental characteristics to be provided shall be compatible with both the article to be measured and the measuring equipment; and finally, the remedial activity prescribed forboth measurement equipment and articles under measurement which exhibit non-conformance.

4.10. Stamp Controls: Chapter 10 has only two subsections, 1B1000 and 1B1001. The first covers a six point stamp control program that the contractor is required to implement and maintain, and the written procedures to be prepared to cover it. The second sub-section contains a restriction stating that contractors' stamps shall not contain the designation'NASA.'

4.11. Handling, Storage, Preservation, Marking, Labelling, Packaging, and Shipping: This chapter covers what controls the contractor is required to provide in the areas denoted by the titles given in the chapter. The coverage is stated in 3 sub-sections, 1B1100 thru 1B1102. Respectively these deal with requirements for handling and storage of hardware, Preservation Marking and Labelling, Packaging and Packing of hardware to obviate deterioration, and control of Shipping of articles by means of a 7 point prescription, covering both hardware and its associated documentation package which is to be shipped with the hardware.

4.12 Sampling Plans, Statistical Planning and Analysis: This chapter has two subsections only, 1B1200 & 1B1201. The first deals with the conditions under which NASA will permit the use of statistical sampling plans and techniques, and the requirement that all such usage requires approval by NASA or its elected representative government agency. The second section deals with the use of statistical quality control methods and associated charts, and the situations and conditions under which such methods are permitted to be employed.

4.13. Government Property Control: This final chapter in two subsections, 1B1300 & 1B1301, defines the contractors responsibility for the care of any/all property furnished by the Government for use with a given program or programs. A 5 point action list is furnished to cover both equipment, and records to be maintained with respect to said equipment, as well as a requirement for functional testing to assure that the equipment is in proper order. The second sub-section requires the contractor to segregate, identify, and notify the Government supplying agency of any damaged, malfunctioning, or non-conforming Government property. None is to be reworked without authorization by the supplying agency.

5.0 Detailed Analysis and Recommendations for Changes: The information contained in this portion of the EM is not intended to be a complete re-write of NHB 5300.4(1B). Rather the intention of this analysis is to treat the document chapter-by-chapter, and paragraph-by-paragraph, in sufficient detail to illustrate either the inadequacy of the document in its present form, or the cost driving contributors, or both. The level of detail given, and the recommendations for changes believed to be cost effective if adopted, are furnished in such a manner as to permit a rapid re-write of the handbook in a more specific form, should NASA elect to implement such a process. This outcome dictated the choice of presentation format for the material. The format presents the left hand side of each page by chapter and subsection as it Is Now. The right hand side of each page shows the subject matter as it is TO BE, assuming that recommended changes are adopted.

5.1. Recommended Combination: Quality Assurance as a discipline embodies both Quality Engineering and Inspection Activities. As an over-simplification, it is the function of Quality Engineering to determine the most effective methods by which the quality of hardware/software may be assessed, and to promulgate standards of workmanship etc. Inspection functions seek to determine that the hardware meets the **quality** standard specified for insurance of proper operation/

end-use function. Methods employed to make such determinations range from the simple, such as go no-go gages, and visual checks of form fit and function, to the complex where optical comparators, electronic metrological devices, cheical processes, and other aids are employed to determine the conformance of hardware/software to the design criteria against which they have been produced. Since the two disciplines go "hand-in-hand" it is difficult to divorce one from the other. LMSC recommends that Inspection and Quality Provisions be combined ultimately into one integrated document. Currently, Inspection is treated as a separate entity forming another part of the NHB.5400 series, specifically, NHB 5300.4(1C).

5.1.1. Example of Combined Document Attempt: In an attempt to provide for the assurance disciplines for the Shuttle Era, NASA has issued a document, NHB 5300.4(1D-1) Safety, Reliability, Maintainability, and Quality Provisions for the Space Shuttle Program. Essentially, this document combines under one cover, NHB 1700.1, NHB 5300.4(1A) MIL-STD-470, and NHB 5300.4(1B). Each still stands as a separate autonomous document, and while there is additional material incorporated into each, to allow such considerations as "refurbishability", turnaround time, hazard analyses, etc; LMSC does not consider that the document has been prepared with Low Cost as the prime criterion. Much of the content is word-for-word repetition of the current unmanned program documents. This document is quite recent, date of issue being August 1974.

5.2. Analysis Tabulation:

Chapter "Is Now"	Chapter "To Be"
Chapter 1. Introduction	Chapter 1: Introduction... No change.
1B100 General: Statement covering requirement necessary to provide effective operation of a quality program for NASA aeronautical & space programs systems, subsystems, & related services.	1B100 General: Stet.
1B101 Relation to Other Contract Requirements;Covers overlapping of other contract rqmts, such as rel, safety &	

Chapter "Is Now"	Chapter "To Be"
1B101 Continued: and test, shall not result in duplication of contractor effort.	1B101 Stet.
1B102 Actions & Prerogatives of the Govt. Covers the fact that all contractor effort is subject to NASA evaluation, review, audit etc. by NASA office procuring or Govt elected alternate.	1B102. This subsection contains items 1,2 &3 item 1 deals with the subject matter as shown at left. Item 2 covers the resident or itinerant basis on which Govt Reps may be assigned. Item 3 covers facilities & services contractor is to provide to Gov't Reps. All Stet. Item 3 should be amended to state uneqivocally what is expected, but this amendment should be elsewhere in the contract preamble, rather than change the statement in this handbook.
1B103 Quality Program Docmts: Reference is made to Appdx A. This Lists 40 program doc'mts all cross ref'd to the HDBK by sub-para number. Any/all are subject to (a) Approval (b) Review. (c) Information. Explanation of these three categories is given. Item 2 requires contractors to generate documents cited and hold them available to NASA.	1B103 . NASA states in CIRL/CDRL which documents it requires in the Approval, Review, and Information categories. Recommend STET for the paragraph, but ADD "Documents requiring NASA approval will be held to a minimum to include only.... per CDRL." "Documents subject to NASA review shall be held to a minimum and include only those agreed essential to the successful prosecution of the quality program; such agreement to take place during contractual negotiations. "Documents required by NASA for information will be held in the contractor's files and furnished to NASA only on request, and in the minimum number of copies possible. Item 2: Recommend deletion, staement is superfluous, contractors are aware of need.
1B104. Glossary of Terms: Defines terms used in this publication.	1B104: Stet.
1B200 Quality Program Mgmt & Planning Outlines a 5 point approach contractor is to take to assure quality. Includes recognition of necessity for all aspects of Quality program, rqmts determined & met, designs include quality, Detection of deficiencies	

Chapter "Is Now"	Chapter "To Be"
1B200 Gen'l (continued) Provision of corrective action.	1B200: The statements set forth are innocuous. For past 15 years every aerospace contractor has maintained such a Quality program routinely Statement does not drive costs, but neither does it add anything to the Hdbk. Recommend deletion.
1B201 Organization. Cites the mandate for a Quality Org'n with one person responsible with direct access to higher mgmt.	1B201 Statement is innocuous. Recommend additional statement, to show one person for each program, to manage Quality functions. Dual reporting authority, (a) Program Mgr in direct line, advisory to overall contractor Quality management.
1B202 Training: Sets forth a 4 point training program, in which Workmanship is to be assessed, operations are to be assessed in terms of care and Safety, personnel are to be certified as proficient in their respective operat'ns recert'fd periodically, and training records kept.	1B202 All major aerospace contractors have on-going training programs of type specified. Rather than inform NASA of fact in every RFP response, and show some costs for training in each cost proposal, recommend: Amend statement to read: Contractor shall maintain a quality training program which NASA will review periodically for adequacy.
1B203 Quality Information: Covers contractor's responsibility to furnish qual info thru-out his org, & to suppliers, on all aspects of prog	1B203 Stet
1B204 Quality Status Rptg Outlines rptg on 4 point basis. Personnel changes(key) Problems & Solutions, performance, & supplier perf'mce.	1B204 Amend statement to include. Wherever possible, contractors shall report these data as part of other program reporting to minimize paperwork, and cost of reporting.
1B205 Quality Program Audits Covers contractors responsibility to check on quality program, all aspects to deter effectiveness. Audits to be random, outcomes reported to higher contractor mgmt.	1B205. Contractors perform such functions routinely, as a matter of business practice. Such a function does not need to be specified. Delete the paragraph.
1B206 Quality Program Plan: Mandates a Quality Program Plan	

Chapter "Is Now"	Chapter "To Be"
1B206 Continued: to be submitted with either RFP response or as per contract) States plan to cover all Qual tasks, separate plans for each remote site, updated periodically. Covers by 4 points exact contents of plan including work-flow charts.	1B206 Every aerospace contractor doing business with NASA has responded to this rqmt for 15 years, for EVERY PROGRAM UNDERTAKEN. LMSC reviews show that each contractor's plan and revisions, closely resembles that of his competition. Apart from the purely paperwork oriented costs, review time is cost driving for all these plans. At current levels of capability contractors do not need to be told how to plan quality activity. Recommend: Section be amended to require a standard quality plan, submitted once yearly by each major contractor, to cover all programs undertaken by and for NASA. Program peculiarities only need be costed and submitted with the RFP response, and these only when significant departures are needed in current quality technology and practices. The plan should include Inspection activity in the standard publication, and only significant departures from norms should require work-flow charts to be prepared new for each program. Off-site peculiarities, and remote site peculiarities only would require update rather than new plans each program.
Chapter 3. Design & Development Controls. Sets forth: 1B300 Technical doc'mts rqmts 1B301 Qual Support to Des.Rev. 1B302 Change Control	Chapter 3. 1B300: States that the contractor shall document all design characteristics & criteria. These statements are not oriented to QA functions and responsibilities. Part 2: Requires that Quality Assurance personnel review all program documentation, for determination of all deficiencies, clarity of statement, unambiguity etc. This also is not a Quality function primarily. Recommend: QA responsibility to check documents be limited to only those directly related to Quality functions. i.e. Quality should not need to check drawings, engrg checkers do this. It is not a QA function to assign, determine, or check characteristic tolerances, only that hardware produced meets the tolerances assigned and checked as valid by engineering. 1B301: QA participation in design reviews should be limited to Inspectability only.

Chapter "Is Now"	Chapter "to Be"
1B301 Continued.	The determination of producibility, and repeatability are not Quality Assurance functions, but rather those of Process Engrg.
1B302 Change Control: Outlines the contractor's responsibility to control all documents and changes thereto, affecting the Quality Program. Requires the change control system to be documented.	1B302. Recommend amending this subsection. Delete the requirement to document the change control & release system, as this would form a part of the standard Qual.Plan. Part.2.Effectivity: Recommend deletion of this clause. Function is a compound one involving program management for scheduling changes, manufacturing for effecting the changes, as well as configuration management to determine they are carried out.
Chapter 4.Identification & Data Retrieval:	
Comprises:	
1B400 General: This requires contractors to develop & maintain an identification & data retrieval system to provide I.D. for operating fab, processing, procurement, inspection & test records. Means of tracing items & mat'l These to be developed along with logistics & config mgmt. Common I/D numbers for all systems.	1B400. This is not a Quality Function. Should be deleted. (Note this, and the ensuing other subparagraphs listed refer to items which on programs such as Atmosphere Explorer have been handled by Configuration Mgmt. This program combined Rel, Qual, & Config Mgmt functions and plans successfully, for approx half the usual assurance disciplies costs.)
1B401 I/D methods. Covers 3 part methodology by date code, lot number, serial no., and other permissible I/D	1B401. Recommend transfer of responsibility to Config Mgmt. deletion from Quality HDBK.
1B402 Documentation: Requires system to be documented.	1B402 Recommend deletion. Transfer to Config. Mgmt.
1B403. I/D Control: Covers traceability of items.	1B403. Recommend transfer to Config. Mgmt.
1B404 I/D List: Covers listing of all articles by number at onset of design activity.	1B404: Recommend transfer to Config Mgmt.
1B405. Records Retrieval.. Requires that records be referenced to articles & mat'ls and records be retrievable readily.	1B405. Recommend transfer to Config Mgmt.

Chapter "Is Now"	Chapter "To Be"
Chapter 5. Procurement Cntrls.	
Covers:	
1B501 General: Contractor responsible for quality of all purchased(contractor) articles, mat'ls, & services.	1B500 1B501: Stet. for both the General statement, and the quality involvement in eval-uation, program and the selection of procurement sources.
1B502 Procurement Documents: Subparagraph covers review of documents as item 1. Data documents must contain as item 2. Item 2 covers sub-items a,b,& c for Supplier Qual Programs. Basic Tech Rqmts. Detailed Qual Rqmts. This latter item 'c' covers 13 subjects: Changes, Purchased Raw Mat'l, Raw Mat'l Used in Purchased Articles, Preserv'n Packaging, Packing & Shipping Age control, & Life Limited Products, I/D & Data Retr'vl Inspection & Test Charact'tcs Insp'n & Test Records, Re-Subm'n of Non conform'g Items or Mat'ls, Contractor QA at Source, Gov't Source Insp'n, Procurements other than those requiring GSE, and Equipment Records.	1B502 Stet for this entire subparagraph in all 13 sections. Quality Review is to assure the inclusion of these provisions in procure-ment documents.
1B503. Contractor QA Person-nel at Source: Permits the contractor to assign QA pers -onnel at suppliers/subcontra -ctors. If so assigned, personnel are to be described in terms of duties to be performed, to Gov't QA Rep. 6 criteria for assignment are listed, one or more of which must exist.	1B503. Stet. But recommend addition of the statement,"To the extend feasible". The costly nature of such personnel assignments should carry a limitation to programs of some given dollar level. For programs at lesser levels, ININERANT QUALITY ENGINEERS/INSPECTORS should be specified as an alternate approach. These can serve several contracts. Note: this is a permitted U.S.Navy practice.
1B504. Gov't Source Inspection	1B504. Recommend Re-word to make G.S.I. sufficient where done. Two costly inspections are unnecessary.
Covers fact that Gov't Source inspection does not absolve contractor from resposibility.	

Chapter "Is Now"	Chapter "To Be"
1B505 Receiving Inspection System Mandates that the contractor shall maintain a receiving inspection system. Sets forth 12 assurances that the system must provide. These are exhaustively specified.	1B505. Stet for the entire subparagraph. There are two alternatives to this recommendation: o If NASA does not combine NHB 5300.4(1C) which covers inspection into a re-write of the Quality Document, delete this entire paragraph and insert it into the (1C) Inspection Document. o If NASA does elect to combine the two documents, this paragraph should be amended to denote which of the 12 assuranc-es are Quality Engineering oriented, and which Inspection services. Currently, there is a mix. For instance, item 8 requires that chemical analyses be performed as required by specs or dwgs on test speciments. Hourly rated inspector personnel can only testify that such has been done. Engineering Test carries out the analyses, and Quality Engineers verify that the results meet performance rqmts.
1B506 Receiving Records. Covers rqmts to keep records of all rcvg insp'n activity, and states minimum contents of such records.	1B506. Either STET Or delete and incorporate into (1C) as with previous item.
1B507. Supplier Rating System Requires contractor's to rate suppliers based on rcvg insp and test results. Outcomes to verify procurement sources.	1B507. STET. Quality Engineers actually per-this rating service.
1B508 Post Award Survey of Supplier Operations: Specifies a three parameter survey of suppliers to be done by a contractor post-award. Covers, complexity criticality of items, supplier quality record, fab/test capability etc.	1B508. Recommend amend to read:"Contractor to perform on first NASA program supplier is used only". Survey is costly, and after qualifying supplier should be maintain on qualified supplier list unless cause arises to change his status.
1B509. Coordination of Contractor-Supplier Inspections and Tests.	

Chapter "Is Now"	Chapter "To Be"
1B509 Continued: Covers requirement for compatibility of inspections/tests contractor/supplier. Contractor gives assistance to this end as rq'd.	1B509. Re-write to show that Test Organization or Inspection services furnish training aids and technical assistance, NOT Quality Org. QA has a surviellance role only.
1B510. Nonconformance Information Feedback. Concerns feedback of non conformance info to suppliers, and assurance of remedial action.	1B510: Re-write to show that Quality Engrg handles feed back loop only. Diagnosis of Nonconformance is effected by Engineering. Quality Engrg handles corrective action follow up and re-certification, and Inspection handles acceptance on next incoming shipment of reworked items.
Chapter 6. Fabrication Control	Chapter 6. 1B600, 601, 602, 603, 604.
Includes: 1B600 Fabrication Operations 1B601 Article & Mat'l Control 1B602 Cleanliness Control 1B603 Process Control 1B604 Workmanship Standards	This chapter illustrates the general nature of the handbook. Provision of the controls called out in this section are the responsibily of manufacturing, process, materials engineering support, materials engineering, and manufacturing planning organizations of a contractor, and/or suppliers. For instance; the quality/Inspection role in cleanliness control is one of surveillance to assure the Federal Standards regulating cleanliness are met. In the case of para 1B604, the Govt & contractor's quality personnel must agree upon the adequacy of the standard. The preparation of the standard sample or visual aid, and the process by which it is produced must be effected by engineering, process engineering, and manufacturing. Recommend: (a) Delete entire chapter, incorporating data elsewhere in other applicable control documents. (b) Re-write to show specific QA and Inspections roles, functions, and responsibilities. In the past QA has assumed the function of effecting the controls described rather than assurance that the functions have been provided by organizations qualified for such purpose.
Chapter. 7. Inspections & Test 1B700 General. Requires contractor to plan and conduct an Inspect'n & Test Program.	1B700. All contractors are aware of this need Recommend: Statements be deleted.

Chapter 'Is Now'	Chapter "To Be"
1B701 Inspection & Test Planning: Sets forth the aims and intents of the Inspection and Testing Operations to be provided by the contractor, & his suppliers.	1B701: Again, the statements are general in nature. They state what is required of the contractor, not what is required as specific activity by his QA personnel/organization. This clause has three actual functions involved (1) Inspection Services. Provides Inspection (2) Test Operations. Plans, Executes Tests (3) Design Engineering: Design sets test limits The QA function is again one of surveillance to determine compliance only, NOT as has been the case, effectors. Recommend: Delete Paragraph/ Re-write to state Quality finite functions.
1B702. Test Specifications: Covers the provision, and preparation of test specs. States what specs are to include.	1B702. Covers the entire gamut of rqmts. Includes Environments, safety, reliability, test parameters & tolerances, adjustments, rework, repair, maintenance, data recording and analysis, re-test, and test results reporting. Role of Quality is only to assure that specs generated include such variables. Recommend: Re-word to show specific quality responsibility only.
1B703. Inspection and Test Procedures. Covers the provision of suitable procedures for regulation of these operations and specific instruction of operating personnel assigned. Give a 13 point outline of content required.	1B703. The inference can be, and in the past has been made, that a contractor's quality organization is to carry out the activity described as necessary in provision of these procedures. Of the 13 points covered, only item 13 Non-conformances is of direct concern to QA. The others concern Test Ops & Planning, Engineering, Safety Engineering, and Inspection Services. The QA function is to assure procedures are available and contents are as prescribed. Recommend: Deletion, and relocation of rqmts in test, ispection, & safety documents; or re-write to show specific QA responsibility.
1B704. End-Item Inspection & Test Specifications & Procedures. Requires provision of separate Test & Inspection procdrs for end-items. These are to simulate end-use, without damage to end-item, and provide a measure of quality. Degree, duration, & number of tests, to demonstrate contract	

Chapter "is Now"	Chapter "To Be"
1B704 Continued: ... compliance, and workmanship merit	1B704: Recommend:Deletion of this subsection. Quality has only surveillance role in this activity .
1B705 Test & Inspection Performance: Covers: 1. Inspections & Tests. To be performed on procured and Fabricated hdwre prior to installation into next higher level. a. Control of Articles b. Control of Inspection & Test Environments & Equipment. c. Criteria for Inspection & Re-Test: 6 criteria are listed. 2. Qualification Test Articles. Lists a,b,c & d controls 3. Requalification Testing Contractor must state need for it, and gain Contracting Officer approval prior to conduct. 4. Qualification by Similarity. States conditions in which NASA will permit it. 5. End-Item Insp'ns & Tests Contractor to effect such to approved specs. Handle non-conformances per Chap 8. 6. End Item Insp & Retest Requries Govt QA approval prior to conduct. 7. End Item Insp & Test REPT Covers format & content of report rq'd.	1B705. All of the requirements & provisions set forth in this complete paragraph, are general instructions only, and refer to what is required in terms of specific tasks and reporting by the executing organizations involved, in this set of cases, Inspection Services, and Test Operations. In some areas, the chapter subsection merges into Chapter 8 as concerns the act-ions of the Material Review Board(MRB) in the disposition of non-conformances. The only function for QA throughout is Surveillance. This may be sub-divided into two parts: o Surveillance, Test Operations & Inspection to assure actions are executed. o Surveillance, Inspection; advisory to assist in the interpretat'n of critieria for inspection. Recommend: (a) Deletion of paragraph. (b) Re-distribution as applicable of these test and inspection requirements into other Test & Requirements for inspection documents; i.e. Mil-Std -810, NHB 5300.4(1C).
1B706. Inspection & Test Records & Data	

Chapter "Is Now"	Chapter "To Be"
1B706 Continued: Requires the contractor to generate and maintain records and data of all tests & insp'n performed. 2. Requires Equipment Records. sub items a thru f list what these records must contain. Subsystem records are to be combined into system records	1B706 All of these records required are re-specified on the CIRL/CDRL. The combination usually takes the form of a system Log Book.) with sub-logs for lower order of equipment as applicable. Inspection Services, in conjunction with Test Operations, enter that each action is performed, inspection personnel performing the inspection, witnessing the tests performed by test operators, and noting that results did/did not meet specifications. If the latter, corrective action is initiated. QA function is to assure that Logs are properly compiled and maitnained current, and that all inspection and Test actions specified have been carried out. Recommend: Re-write to define QA function specifically.
1B707. Contractor Quality Assurance Actions. Cites QA activity prior to inspection and Test operations. Cites QA action during Test Operations.	1B707. Stet. All Items Listed. This is a properly formatted set of statement of specific QA responsbility. It is directly) applicable to the Quality Assurance organization maintained by a contractor, and details WHAT is to be done, WHEN, and by WHOM. If NASA elects to re-write this section of the HDBK recommend this format and approach be used.
Chapter 8. Non-Conforming Article & Material Control Includes: 1B800. Statement of Policy 1B801. Specifies Documentation Rq'd & Contents 1B802 Remedial & Preventive Action: Cites non conformance diagnosis methods of remedial action implementation and notification 1B803. Initial Review Dispositions. Item 1a. Covers Rework, Item b Covers Scrap. Item c. Covers Return to Supplier. Item 2 Covers Review of items dispositioned without MRB action.	

Chapter "Is Now"	Chapter "To Be"
1B803 Contn'd. Item 3. Requires Initial Dispositions to be documented 1B804 Material Review Board. Sect.1 Defines Membership Sect 2. Defines Responsibility Sect 3. Defines Dispositions 1B805 Written Requests for NASA Contracting Officer Approval: Coverse conditions under which approval must be sought for dispositions where the contractor recommends Repair or USE-AS-IS 1B805.Supplier MRB Permits MRB activity to be delegate to suppliers, with NASA approval.	The entire chapter adequately defines the membership, responsibilities, activities, and dispositional activities of a material review board, instituted for handling non conformances. As such it is a highly formal activity, and was intended originally to apply to large scale, high financial involvement programs. Its chief problem is that it can, and does inject delays into program schedules, by the mere fact that a board must be convened, each time dispositions require handling, as most programs cannot afford a direct full-time board Secondly, Contracting Officer approval is required under several conditions, and this can also inject delays. In practice, contractors are required to formulate and maintain a Quality Assurance Manual. This document covers the totality of Quality Assurnace Functions and responsibilities. Usually, it contains MRB and non-conformance handling procedures tailored to a FULL Conformance, Limited Conformance, and Informal Activity set of scales. Based upon prior contractual agreements, one of these alternatives is selected. Years of Program experience has proved the effectiveness of the second two levels, which are dictated by the complexity and dollar value of a program. Recommend: Chapter be re-written to allow maximum informality, minimum documentation, and rapidity of disposition in accordance with proved program scaled methods.
Chapter 9. Metrology Controls Includes: 1B900. General: Contractor to establish & maintain metrology system to evidence quality conformance. 1B901 Acceptance: Mandates conditions under which contractor is to check stds prior to acceptance. 1B902. Evaluation:All stds (incl auto check out equip) to be verified for:	

Chapter "Is Now"	Chapter "To Be"
1B902 Cont'd: 1. Accuracy of measurement of desired characteristics 2. hadware configuration compatibility 3. Correctness of Operating Instructions. Records to be kept of eval'ns 1B903 Article or Mat'l Measurement Process. Mandates random & systematic errors in article/mat'l measurement process not to exceed 10% max of article tolerance Excp'ns, to be authorized by NASA. 1B904 Calibration Measurement Process: Mandates randon & systematic erros not to exceed 25% of tolerance of parameter measured. NASA appro for excp'ns. 1B905 Calibration Controls: Specifies a 7 point control process & permits internal or external facilities for calibration of stds used by contractor. Controls are Traceability, Handling/storage I/D & Labelling, Calib Interval, Recall System, Calib Records and their contents. 1B906 Environmental Rqmts Specifies environmental rqmts compatible with accuracy of stds. 1B907. Remedial & Preventive Action: non conforming stds & hdwre measured by them shall be subjected to these actions	Chapter 9: All of the requirements of this chapter are valid as such. All aerospace contractors and suppliers are familiar with these requirements/controls, and these are the subject of both Federal Stds, as well as DoD tri-service stds. Further each contractor, and supplier is obliged to include in his Quality Manual, a detailed description of his Measurements & Standards facilities, whether his own, or those of externally procured origin The directive of this chapter apply to the Measurements and Standards activity, and check to assure that all functions are carried out is customarily perofmed by Inspection Services. The specific role of Quality Assurance is once again that of a check and balance to ensure proper execution of these requirements takes place. Recommend: Delete this entire chapter. Alternatively: Describe this activity once, in a standard Quality Program Plan, subject to NASA approval. Update description periodically as necessary. This will save, as a minimum the expense of describing the entire system every time a quality program plan is generated and submitted in response to every single RFP.
Chapter 10: Stamp Controls: Mandates a 6 point controls system with written proc'drs for stamp control.	Suggest Deletion: In force universally for 15 years, part of every contractor's approved Manual of Quality & Inspection Practices. For 1B1001 Stamp Restriction: Stet (No NASA)

Chapter "Is Now"	Chapter "To Be"
Chapter 11. Handling, Storage, Preservation, Marking, Labelling, Packaging, Packing & Shipping. 1B1100. Handling & Storage Mandates: Protectiion against handling damage, special handling isntructions as rq'd, evidence of periodic proof testing of handling equip'mt. 2. Suitable storage precautions & measures to guard against deterioration & damage, as well as date indicators for critical life items. 1B1101. Preservation, Marking & Labelling, Packaging & Packing: Item 1 Covers Preservation rqmts. Item 2 Covers Marking & Labeling rqmts. Item 3 Covers Packaging. Item 4 Covers Packing Rqmts. 1B1102 Shipping: Item 1 Mandates a 7 point a-thru-g shipping control set of rqmts. Item 2. Documentation Package Mandates that a contractor include a complete doc'mtn package with his shipment. Specifies in general terms req'd contents of package.	Chapter 11: All of the subjects set forth in this chapter are valid in themselves, and all have specifications regulating contractor performance of these tasks, as well as each task being specified in either a contract statement of work SOW, or a Work Breakdown structure (WBS) or both. In practice these tasks are undertaken by specific organizations within a contractor's org structure, such as Materials Handling Engineering, Packaging Engineering, and Shipping. Frequently these orgs are lowers echelons of a formal Engineering Support organization. Regardless of the organizational structure, the tasks are require(s)-d contractually to be described and costed and contractors have suitable specifications and instruction manuals for the regulation of this work. Specifically, Inspection services checks each step in these tasks/processes, against spec/procedures provided. The role of QA is once more a surveillance function, and signature to certify that the tasks are performed as specified. Recommend: This paragraph be deleted as superfluous.
Chapter 12. Sampling Plans; Statistical Sampling & Analysis. 1B1200 Sampling Plans: Covers conditions under which NASA will permit contractor use of sampling plans. 1B1201: Same coverage for use of statistical analysis	Chapter 12. Statistical Quality Control is a well established methodology. NASA SOWs routinely require a contractor to recommend the use of sampling plans & statistical techniques, all of which are covered in many DoD, NASA, & Fed'l specifications, & in contractors QC Manuals. Recommend: Deletion of the chapter as superfluous. In practice few contractor space programs have large populations of items. Inference is usually made by the "Small Samples" technique

Chapter "Is Now"	Chapter "To Be"
Chapter 13. Gov't Property Control: Covers: 1B1300 Contractor's Responsibility: Defines the responsibility of the contractor to account for, and maintain in good order, all Gov't Furnished Property. Further cites a 5 point procedure & action list to be used in effecting this task. 1B1301. Unsuitable Gov't Property. Mandates that Gov't be notified of any property that contractor finds to be unsuitable for use for any reason. No dispostion is to be made without Gov't permission.	Chapter 13. All aerospace contractors and suppliers are familiar with this mandate. Further, the mandate is made an article of contractual obligation and compliance is to be demonstrated by the contractor's accounting system. Recommend: This chapter be deleted from the NHB as superfluous.
Appdx. A. Quality Program Document Corss Reference Index References each Quality Doc't to Chapter, by para number and page number of NHB 5300.4(1B) 40 Documents in all, by count. No sub-tiers included.	Appdx.A. Stet Pro-Tem. Should NASA elect to re-write NHB 5300.4(1B) which would in all probability eliminate the need for some of the quality documents, this appendix would require alteration accordingly.
Appdx. B. Glossary of Terms: Defines terminology used in NHB 5300.4(1B)	Appdx B: Stet Pro-Tem. Should revision of this document result in the use of more, less, or different terms from those listed and defined, the appdx. will require revision accordingly.

6. Cost Estimate Associated with Use of NHB 5300.4(1B)

6.1 Basis for estimates: Appendix A of the Quality NHB lists 40 documents, any or all of which may be mandated as deliverable under the contractual requirements of a typical NASA Space Program. The Appendix has been included in this E.M. to provide a ready reference, and forms the text of pages 28 & 29. Each of the documents listed requires some preparation time, and each document furnishes a record, or an outcome of a specific Quality Assurance task undertaken as part of the assurance workload. While LMSC has performed relatively few contracts for NASA, the NASA documents are also required in either identical form, or similar form, by USAF contracts; performance on which forms the bulk of LMSC SSD experience in the design and fabrication of high quality, reliable space vehicles. The documents listed, together with the tasks to which they relate, comprise the quality assurance programs undertaken to date, to a large extend. Under certain assumptions and provisos, the documents form the basis for these estimates which follow.

6.2. Estimate Constraints: It cannot be emphasized to strongly that the estimates represent the experience of one aerospace contractor, LMSC. The estimates are under no circumstances to be considered indicative of the magnitude of quality expenditures which may be experienced on future vehicle contracts. They are useful only in that they afford some measure of what compliance with the requirements of NHB 5300.4(1B) have cost NASA historically.

6.3 Assumptions for Estimates: The following assumptions have been made:

(a) Estimates are made on the basis of assumed full compliance with all of the requirements of NHB 5300.4(1B)

(b) Assumption is that all of the documents listed in Appdx.A have been prepared for a given program (or a similar set of documents)

(c) Many of these documents listed in Appdx. have specific NASA formats, and in many cases NASA forms are supplied to a contractor. Assumption is that time to prepare/time to complete a document; i.e. fill it out, are interchangeable as a basis for estimates.

APPENDIX A: QUALITY PROGRAM DOCUMENT CROSS-REFERENCE INDEX

Page	Document	Par.
2-2	Training Documents	1B202-1
2-2	Training and Certification Records	1B202-4
2-2	Quality Information	1B203
2-3	Quality Status Report	1B204
2-3	Quality Program Audit Reports	1B205-3
2-3	Quality Program Plan	1B206
2-4	Policies and Procedures	1B206-2b
3-1	Technical Documents	1B300
3-1	Document Review	1B300-2
3-1	Change Control System Document	1B302
4-2	Identification List	1B404
5-1	Quality Records	1B501-1
5-1	Pre-Award Survey Results	1B501-2
5-1	Procurement Documents	1b502-1
5-6	Receiving Records	1B506
5-6	Post-Award Survey Schedules	1B508-1
5-6	Post-Award Survey Results	1B508-3
6-1	Fabrication Documents	1B600
6-2	Process Control Procedures	1B603-2
6-2	Equipment Certification Records	1B603-3

NHB 5300.4(1B) Appendix A.Cont'd

Page	Document	Par.
6-2	Workmanship Standards	1B604
7-1	Inspection and Test Planning	1B701
7-1	Test Specifications	1B702
7-1	Inspection and Test Procedures	1B703
7-2	End-Item Inspection and Test Specifications and Procedures	1B704
7-5	End-Item Inspection and Test Report	1B705-7
7-5	Inspection and Test Records and Data	1B706-1
7-5	Equipment Records	1B706-2
8-1	Nonconformance Documentation	1B801
8-4	Written Requests for NASA Contracting Officer Approval	1B805
9-1	Procedures for Measurement Processes	1B900
9-1	Results of Evaluations	1B902-3
9-2	Calibration Records	1B905-7
10-1	Stamp Control Procedures	1B1000
11-1	Handling Instructions	1B1100-1
11-1	Storage Procedures	1B1100-2
11-1	Packaging Procedures and Instructions	1B1101-3
11-2	Documentation Package	1B1102-2
12-1	Sampling Plans	1B1200
13-1	Government Property Records	1B1300-4

6.4 Tabulations of Quality Cost Estimates/Ranges: The tabulations which follow reflect LMSC SSD & R&D program experience in the domain of quality costs. Table 1. is a compilation of general quality cost statistics, most of which have been published in other E.Ms on the subject of Low Cost Managemement Practices. These data illustrate the range of costs to be expected when NHB 5300.4 (1B) or other equivalent document such as MIL-Q-9858A is fully implemented during a space vehicle program.

6.4.1. Tabulation 1:

Quality Programs; General Statistics

#	General Quality Program Costs/Ranges. (in Percent Total Program Costs)
1	For typical space programs in the 50-100 million cost range Quality Costs range from 7-11% TPC.
2	Quality Costs for typical space programs range from 34-45% of Manufacturing costs
3	Typical Space Program Quality Engineering Costs range 23-37% of Quality Program Costs (QPC) Typical Space Program Inspection Services Costs range 63-77% of QPC Typical ratio; QE to Inspection...................... 1:3 approx.
4	Economies possible: Atmosphere Explorer (RCA/GSFC) Quality Costs: 3.8% TPC. Economies Attributed to: Integration of Quality/Inspection, Reliability & Configuration Management Effort and Planning.

6.4.2. Quality Documentation Costs: Based on the Quality Program Documents List which forms Appdx. A. of NHB 5300.4(1B) LMSC costs to compare/compile quality documents have been tabulated. All these are average values and are given in manhours as the basic cost compilation/collection unit. Again, these values represent average charges, and times allowed to quality program personnel to perform the tasks of preparation/compilation of the documents.

Quality Document Title &Action	Orientation QE	Insp.	Mh to Prepare/compile
Training Documents (prepare)	X	X	Approx 40 hrs each
Training & Certification Records		X	Approx 20 hrs per case
Quality Information Reports (prepare)	X		Approx 20 hrs each
Quality Status Reports (prepare)	X		Approx 20 hrs each
Quality Program Audits (prepare)	X	X	40-80 hrs each depending on program size.
Quality Program Plan (prepare)	X		40-160 hours, depends on program size/complexity
Quality Policies & Procedures.	X	X	30-40 mh each issue.
Technical Documents (review only)	X		10-20 hrs, depends on size & complexity.
Document Review (general documents such as P.O.s etc)	X		2-4 hrs per issue copy.
Change Control System Documentation	X		10 hrs per change approx
Identification Lists (review only)	X		8 hrs per listing.
Quality Records (compile & issue)	X		20-40 mh per record
Pre-award Surveys (reporting only)	X		40-60 mh per survey
Procurement documents (complete pkgs)	X		8-16 mh per package.
Receiving Records. (review/prepare)	X	X	4-8 hrs per issue.
Post Award Survey Schedules. (prepare)	X		8-12 hrs each issue.
Fabrication Documents (review)	X		20-40 hrs each pkg.
Process Control Proc'drs(review)	X		4-10 hrs each issue.
Equipment Certification Records(rev)	X		2-4 hrs each issue
Workmanship Stds. (prepare/Compile)	X		20-40 hrs per std.
Inspection & Test Planning (review plan inspections)	X	X	40-80 hrs per plan
Test Specifications (Review &cert)	X		10-20 hrs per spec'n
Inspection & Test Procedures (prepare Insp'n procs Review Test)	X	X	10-20 hrs per proc'dr.
End-Item Test & Insp'n Procedures (prepare Insp'n procs Review Test)	X	X	10-20 hrs per proc'dr.
Inspection & Test Records & Data (review & compile/distribute)	X		Assumes a data system -20-40 hrs per issue/tes
End Item Insp'n & Test Report (Compile Insp'n, Review Test info)	X		40-60 hrs per each.
Equipment Records (review/update)	X		2-4 hrs per each.
Non-conformance Documentation (prep)	X	X	Varies widely, depends on discrepancy levels.
Written Requests for NASA COR approvl (QA prepares for program)	X		2-4 hrs per copy.
Proc'drs for Measurement Process (rev)	X		10-20 hrs per review.
Results of Evaluations (review)	X		2-4 hrs per issue.
Calibration Records (review/update)	X	X	1 hour per equipment.
Stamp Control (maintain)	X	X	Overhead Charge
Handling Instructions (review)	X		2 hrs per each instr'n
Storage Proc'drs. (review)	X		2 hrs per each proc'dr.
Pkging Proc'drs & Instr'ns (review)	X		2 hrs per each document
Documentation Pkg (compile)	X		8-16 hrs per package
Gov't Furnished Property (Maintain)	X		2 hrs per item if any.

Tabulation 2. Quality Documentation Costs.

6.4.3. Quality Engineering & Inspection Programs; Major Tasks Costs:

Tabulation 3. furnishes cost estimates for those major tasks, carried out on typical programs where full compliance with NHB 5300.4(1B) is mandated by NASA. The tasks are identified from the quality documents list which forms Appdx A to the NHB document, and bear a cross reference number accordingly. In some cases, where a quality or inspection task falls within more than one category as regards documentation, two or more of the cross referencing numbers appear against the task. The assumption is that these tasks are performed, as indeed they are on a typical program, and a Quality Activity WBS has been prepared against which costs are acquired per task.
All cost values are given in Percent Quality Program Costs, and the entire spectrum of both the Quality Engineering and Inspection Services task activity is summarized and shown in Percent Total Program Costs (TPC).

Ref	Major Quality Tasks; Typical Quality WBS (internal)	%QPC	%TPC
1B206-	Quality Management	1.55	2.5
1B501	Vendor/Supplier Surveys	0.55	
1B300/500	Quality Documentation (Preparation & Updates)	4.00	
1B205	Quality Audits	0.35	
1B206	Quality Planning (Inspec'n & Test, Work-flows & Plans)	1.20	
1B300	Quality Liaison (Engrg & Engrg Support Services)	2.40	
1B600	Quality Liaison (Mfrg, & Mfrg Support Services)	7.10	
1B703	Quality Liaison (Test Operations, & Test Support Svcs)	2.20	
1B706	Quality Data Retrieval, Reduction, & Reporting	3.50	
1B703	Inspection Services Liaison	3.20	
1B801	MRB & Corrective action Follow-up. (average only)	1.50	
1B905	Measurements & Stds Lab, Liaison & Control	0.25	
1B202	Quality Training, & Certification	0.70	
1B805	Customer (NASA) Liaison	1.50	
Ref	**Major Inspection Svcs Tasks; Typical QWBS (internal)**	**%QPC**	**%TPC**
1B701	Inspection Services Management	2.25	6.0
1B202	Inspectors Training & Certification	2.50	
1B704	Quality Engineering Liaison	3.20	
1B506	Receiving Inspection	12.50	
1B600	In-Process Inspection	26.40	
1B705	End-Item/Final Inspection	5.15	
1B704	Test Surveillance	12.50	
1B801	Non Conformances Reporting	3.50	
1B1101	Pre-Shipment & DD-250 Inspection Activity	1.25	
1B905	Calibration Inspection (Measurements & Stds Lab Liaison)	0.50	

Tabulation 3. Quality Engrg & Inspection Major Tasks Costs

Lockheed Missiles & Space Company

ENGINEERING MEMORANDUM

TITLE: SE&I Cost Impact Analysis	EM NO: LCPP - 8 REF: DATE: 4-21-75
AUTHORS: J. B. Forsyth	APPROVAL: ENGINEERING SYSTEM ENGRG D. L. Hannaford

Section

SYSTEM ENGINEERING AND INTEGRATION COST IMPACT ANALYSIS

.1 Background

The study of Systems Engineering and Integration (SE&I) cost impact on unmanned spacecraft program costs was undertaken as a part of the Low Cost Program Practices Study. The analyses in this area were to include all the systems engineering tasks and costs and the engineering integration activities encompassing the software of "paperwork" interfacing, but eliminating the physical/actual hardware integration.

.2 Objectives and Approach

The objectives of this task was to determine the costs of SE&I activity, the functions and practices which contribute to this cost, and to identify and recommend alternative practices which could reduce the SE&I costs in the future. The approach to this analysis is outlined below:

- o List and describe the typical SE&I functions performed.
- o Determine from the historical data, supplemented by estimates where necessary, the cost vs function for each function. Summarize totals by SE&I function and program.
- o By comparison with each total program cost (TPC) determine the percent of TPC for each SE&I function, percent of each program and average for all programs.
- o Propose candidate alternate SE&I approaches which will tend to reduce or eliminate some of the costs.

- Two separate conditions will be applied:

  That the modified practices were to be implemented on current programs (essentially like the historical program used as a data base).

  That modified practices were to be implemented on Shuttle-era payloads utilizing modularized spacecraft and refurbishable/reusable standard components and/or modules.

- Estimate the cost savings in terms of average total program cost which would result from implementation of the low-cost practices.

.3 Data

The SE&I data sources and availability are shown in Fig. 6-1. As listed, only limited data were obtained at the top level with very few breakdowns by function and associated costs. In addition to the programs listed in Fig. 6-1, top level systems engineering costs were obtained for several Mariner Mars programs but with no insight as to functional breakdown.

The data for the paperwork integration activity are almost non-existent and the only integration costs available have to do predominantly with the physical hardware integration, which was not to be included in this SE&I analysis. The separation of these integration costs is not possible. It appears that most of the engineering integration is changed to design engineering and is not separable from that cost category either. Therefore, the integration part of SE&I effort was eliminated from further analysis.

Program	Agency	Contr.	WBS Item Assigned	Gen'l. Descr. Avail.	Categ. Brkdn. Avail.	SE&I Plan Avail.	SE&I O.A. $ Avail.	SE&I Funct. $ Breakdwn	SE&I Categ. $ Breakdwn
ERTS	GSFC	GE	-	-	-	-	-	-	-
Nimbus - G	GSFC	GE	-	-	-	-	-	-	-
OSO-I	GSFC	Hughes	N	Y	Y	Y	Y	N	N
HEAO - A, B, C	MSFC	TRW	Y	Y	Y	Y	N	N	N
Pioneer-Venus	ARC	Hughes	-	-	Y	-	-	-	-
Pioneer 10, II	ARC	TRW	-	-	-	-	-	-	-
ATS-F	GSFC	Fairch.	Y	N	N	N	Y	N	N
AE	GSFC	RCA	Y	Y	N	N	Y	(Y)	N
MVM-73	JPL	Boeing	Y	Y	N	N	Y	N	N
SMS	GSFC	Philco	-	-	-	-	Y	N	N
71-2	AF	LMSC	N	N	Y	N	Y	Y	Y

N = None   Y = Yes (data available)   (Y) = Yes (some data)

Fig. 6-1 SE&I Data Sources/Availability

The systems engineering data were analyzed at the top level only due to lack of recorded detail at functional breakdown levels.

.4 Lack of Commonality

The term "systems engineering" is a very broad one encompassing many different functions and, as practiced by the space industry, these functions and who performs them vary from program to program and company to company depending on company's/agency's organizational structure.

Fig. 6-2 lists six spacecraft programs and the systems engineering functions performed on these programs as found in the reference material studied. This is not to be interpreted that some of the other functions listed were not performed on a given program, only that a reference was not found under systems engineering function discussions. The non-referenced functions may have been performed by other engineering organizations, by program management staff, or not required on a given program to be performed by the specific contractor. Frequently, especially if the program is in final design/production phase, some of the systems engineering functions have been performed in prior phases or by the customer agency internally.

As can be seen from Fig. 6-2, there is little consistency among the six programs as to what systems engineering functions were performed, except that they all did "allocation of performance design requirements" which is one of the basic systems engineering functions. All systems engineering functions are listed as defined by MIL-STD-499A in Fig. 6-3. Fig. 6-4 lists systems engineering functions defined by MIL-STD-881. There is considerable overlap in the two definitions, but there are also differences.

Function Performed	MIL-STD 499A Category	Program (Contractor) AE	HEAO	OSO-1	MVM 73	Pioneer-Venus	71-2
Mission Requirements Analysis	2.1	X	X	X	X	X	X
System Functional Analysis	2.2	X	X	X	X	X	X
Allocation Performance/Design Reqts.	2.3	X	X	X	X	X	X
Preliminary Design & Synthesis	2.4		X	X	X	X	X
Logistic Engineering	2.5		X				
Life Cycle Cost Analysis	2.6		X				
Optimization Tradeoffs	2.7		X			X	
Production Engineering, Analysis	2.8		X				
System & Item Configuration Specs	2.9		X	X		X	X

Fig. 6-2 System Engineering Functions Performed on Programs (1 of 2) (Preliminary)

Function Performed	MIL-Std 499A Category	Program (Contractor)							
		AE	HEAO	OSO-I	MVM 73	SMS	Pioneer-Venus	71-2	Nimbus-G
System Test Planning	1.3			X					\
Engr. Change Analysis/Control	1.4			X					
Technical Reviews	1.6			X					
Prepare/Control Engr. Dwgs.	-						X		
Conduct or Assist in Test Prog.	-			X			X		
Perform & Review Breadboard & Model Testing	-						X		
Ground Test & Flight Data Anal.	-			X	X				
Support Launch & Mission Ops.	-			X					
Control Budgets & Schedules	-			X					
Interface Comp. (S/C, LV, Exper.)	-		X				X		\

Fig. 6-2 System Engineering Functions Performed on Programs (2 of 2) (Preliminary) (Cont.)

1. TECHNICAL PROGRAM PLANNING & CONTROL

1.1 CWBS and Spec. Tree

1.2 Program Risk Analysis (Cost, Schedule, Technical)

1.3 System Test Planning

1.4 Decision and Control Process (Problem and alternative analysis)

1.5 Technical Performance Measurement

1.6 Technical Reviews (Sys. Reqts, Sys. Des., Prel. Des., Crit. Des.)

1.7 Subcontractor/Vendor Reviews

1.8 Work Authorization

1.9 Documentation Control (Per MIL-STD-480, Config. Mgt.)

Titled "Engineering Management"

2. SYSTEM ENGINEERING

2.1 Mission Reqts. Analysis

2.2 System Functional Analysis (Mission, Test, Production, deployment, support)

2.3 Allocation of Performance/Design Reqts. (to hardware, computer programs, procedures, facilities, personnel)

2.4 Prel. Design and Synthesis (Assure completeness of perform/design allocations)

2.5 Logistic Engineering (Logistic support, maintenance, repair level analysis)

2.6 Life Cycle Cost Analysis (Iterative; economic impact of design alternatives)

2.7 Optimization Tradeoffs (Risks, tech perform., schedule, life-cycle costs)

2.8 Production Engineering Analysis (Materials, Tools, Test Eq., Facilities Personnel for Manufacturing)

2.9 System and Item Configuration Specs (Program-peculiar items)

Fig. 6-3 System Engineering Definition — MIL-STD-499*

- System Definitization and Overall System Design
- Design Integrity Analysis
- System Optimization
- Cost/Effectiveness Analysis
- Weight and Balance Analysis
- Intra-and Inter-system Compatibility Analysis
- Program Requirements for:
    - o Reliability, Maintainability, Safety, Survivability
- Human Engineering and Manpower Factors Program
- Preparation of Equipment and Component Performance Specs
- Logistics Support Integration
- Design of Test and Demonstration Plans.

* "Work Breakdown Structures for Defense Materiel Items"; invoked by MIL-STD-499A.

Fig. 6-4 System Engineering Definition – MIL-STD-881*

Figures 6-5 and 6-6 show the WBS breakdowns for systems engineering as involved on two NASA programs - Atmospheric Explorer (AE) and HEAO. The HEAO definition is much mcre comprehensive and includes integration activities, the AE breakdown is simpler and includes the three basic systems engineering functions only. For other programs, WBS breakdowns for systems engineering were not available. The main point of these figures is that neither SE&I definitions nor WBS breakdowns are specific or consistent. These practices create confusion in systems engineering records from program to program as to what was done under that lable and where was the cost charged.

C-2

		MIL-STD-499A Category
201	<u>Mission Analyses</u>	
	Orbital analysis, orbital parameters, trajectory plots, orbital perturbations, major operational events, etc.	2.1
202	<u>Systems Requirements</u>	
	Overall spacecraft system design and engineering requirement. Includes spacecraft system definition and assurance of design and functional compatibility between the various subsystems.	2.2 2.3
203	<u>Interface Requirements</u>	
	Insure interface compatibility between the spacecraft and launch vehicle/shroud, the engineering measurements GFE, the GFE range and range rate, and the GFE tape recorders.	2.3

* Excerpts from WBS

Fig. 6-5 AE Systems Engineering (WBS 200)*

SYSTEM ENGINEERING CATEGORIES	MIL-STD-499A Category
• Mission & Requirements Analysis	2.1
• Functional Analysis	2.2
• Requirements Allocation	2.3
• Tradeoff Studies	2.7
• Design Optimization Effectiveness Analyses	2.7
• Synthesis	2.4
• Technical Interface Compatibility	-
• Logistics Support Analysis	2.5
• Producibility Analysis	2.8
• Generation of Specs	2.9
• Other SE Tasks	1.5, 2
• Preparation of Design Ref. Mission	-

WORK BREAKDOWN STRUCTURE

- B HEAO SE&I
  - B1 Sys. Eng. & Sustaining
  - B2 Flight Mechanics
  - B3 Electrical Des. Integr.
  - B4 Mech. Des. Integr.
  - B5 Thermal Des. Integr.

* Excerpt from TRW 26000-901-000, Vol. 1, Book 2
"Systems Engineering Management" dated April 1, 1974

Fig. 6-6 HEAO – A, B, C System Engineering & Integration Definition*

.5 Systems Engineering Costs

The cost data for contractor systems engineering on six spacecraft programs is shown on Fig. 6-7. These costs are actuals as changed by individual programs to systems engineering as a general function. In terms of percent of total program cost, systems engineering ranges from 2.8% to 11.4% as shown in Fig. 6-7. The average for this six program sample is 6%. Expanding the sample to 11 spacecraft programs, with Mariner Mars and other spacecraft programs with less firm systems engineering cost data, the average systems engineering cost is 5.4% of total program cost representing little change from the previous 6% average.

How accurately the 6% average represents systems engineering cost contribution to a spacecraft program is debatable. The reasons are:

1. Records from only three programs provide insight below the top cost level.

2. To what degree systems engineering functions were performed by the contractor on these programs as opposed to other program requirements is unknown; and

3. How much of systems engineering effort, by definition, was in reality charged to SE accounts and how much was charged somewhere else is also unknown.

Figure 6-8 shows the breakdown of systems engineering (SE) costs as incurred on the Air Force SESP 71-2 program. Total SE percentage was 11.4% of program cost, composed of 6.7% due to requirements, 4.5% due to analyses, and 0.2% attributed to meetings and reviews. Figure 6-9 presents the systems

Spacecraft Program	Cognizant Agency	S/C Contract	System Engr. Cost	Total Program Cost	Avg. Year Expend.	S.E. % of T.P.C.*	Type** Program
OSO-I	GSFC	Hughes	$2.772M	$34.281M	71/72	8.1%	F/O
ATS-F	GSFC	Fairchild	4.3 (E)	75.4 (E)	71/72	5.7%	F/O
SMS	GSFC	Philco	3.117	42.027	71/72	7.49%	New
AE	GSFC	RCA	0.856	21.761	72/73	3.9%	F/O
MVM-73 (Part #2 Only)	JPL	Boeing	1.075	38.597	71/72	2.8%	New: HI
71-2	AF	LMSC	1.378	12.026	70/71	11.4%	New: HI

Average

*Spacecraft Contractor Program

**HI = High Inheritence

(E) Estimated

Fig. 6-7 Costs of System Engineering

SE&I Function	Cost	% TPC.	MIL-STD-499A Category*
• Program Review, Meetings, Customer Interface	$.019M	0.2%	1,2
• Requirements	$.812M	6.7%	
• Contamination	$.286M	2.4%	2.3
• AGE/GHE Requirements	.036	0.3%	2.3
• Integrated Test Program Requirements	.209	1.7%	2.3
• Launch Ops. Support/Test Requirements	.021	0.2%	2.3
• Launch Ops. Support Orbital Ops. Planning	.148	1.2%	2.3
• Launch Ops. Support Vehicle Sys. Requirements	.025	0.2%	2.3
• Mission System Analysis	.034	0.3%	2.3
• Integrated On-Orbit Ops/Planning	.054	0.4%	2.3
• Analyses	$.547M	4.5%	
• Orbit Thermo Post-Flight Data	.103	0.8%	2.2
• Structural	.130	1.1%	2.2
• Aero-Mech.	.211	1.8%	2.2
• Mass Properties	.050	0.4%	2.2
• Launch Entry Thermo	.010	0.1%	2.2
• Gen'l Space Tech. Coord/Control	.044	0.3%	2.2
Total	$1.378M	11.4%	

Fig. 6-8 SE Functions Vs. $ On SESP 71-2

	Cost	% TPC	MIL-STD-499A Category
• Systems Engineering	$1.184M	3.5%	2.
• Systems Analysis	.788	2.3%	2.2
• Software Plans and Test Support	.137	0.4%	2.3
• Software Program and Test Support	.574	1.7%	2.3
• Program Requirements and Support	.089	0.2%	2.3
Total	$2.772M	8.1%	

Fig. 6-9 SE Functions Vs $ On OSO-I

engineering cost breakdown as reported on the OSO-I program. Total percentage is 8.1% of program cost. Systems engineering plus requirements add up to 3.7%, systems analysis is shown at 2.3%, and software/test support represent the remaining 2.1%.

On Atmospheric Explorer, the breakdown of systems engineering costs was: requirements 3.3%, analyses 0.6%, adding to total 3.9% of total contractor program cost.

Figure 6-10 presents comparable SE breakdowns for the three programs in terms of precent of total contractor program cost. Eliminating the stringent payload peculiar contamination control requirements from SESP costs makes them fairly comparable to OSO-I breakdowns providing an average for the two programs:

o S.E. requirements	4.2%	Total program cost
o S.E. analyses	4.3%	Total program cost
Average S.E. total	8.5%	" " "

This implies that systems engineering effort due to requirements and that due to analyses is about equal, at least on those two programs. The comparison with Atmospheric Explorer (AE), shows that very little analysis was done by systems engineering and the requirements functions were less costly. This is most likely due to the fact that AE is a follow-on program with high inheritance and little or no new technology.

The S.E. costs reported for MVM '73 (Part 2 of Boeing contract) represent 2.8% of spacecraft contract cost (Fig. 6-7). This S.E. cost does not include other S.E. functions (by LMSC's definition, not by Boeing's) such as:

BREAKDOWN	SESP 71-2	OSO-I	SESP & OSO-I AVE.	AE-(C, D, E)
S. E. Requirements	4.4%*	4.1%**	4.2%	3.3%
S. E. Analyses	4.6%	4.0%**	4.3%	0.6%
Total	9.0%	8.1%	8.5%	3.9%

*SESP ADJ. 6.8% - 2.4% for extensive payload peculiar contamination control requirements. (See Fig. 6-8)

**OSO-I breakdowns as allocated from Fig. 6-9.

Fig. 6-10 Systems Engineering Cost Breakdown by Two Primary Functions (As % of Tot. Prog. Cost)

o Contamination Control Requirements		0.1%
o Environmental Requirements		1.3%
o Structures & Dynamics Analyses		1.9%
o Mass Properties Analyses		0.6%
o S/C Configuration & Interface Control		0.3%
	Total	4.2%

Adding the basic 2.8% to the 4.2% would raise the S.E. effort to 7.0% of MVM '73 Part 2 program cost.

There may be other S.E. functions included in MVM '73 subsystem or other work packages for which costs are not extractable. (The Part 1 of MVM '73 contract with Boeing contained some systems engineering effort.)

As in some other planetary programs, which average only 4.4% of program cost for S.E. functions, the NASA agencies may have performed most of the early systems engineering functions in-house and there are no data available on that effort. Estimating the total MVM '73 SE&I effort results in over 9% of total program cost including experiments.

The above discussion is intended to point out that some systems engineering and paperwork integration costs are buried on most programs in other functional cost categories or charged to subsystem engineering and cannot be extracted for analysis.

Since systems engineering is often done by personnel in program office, an attempt was made to combine the costs of program management with systems engineering and plot against the total program cost. Figure 6-11 shows these data. Many programs do not separate configuration management and data costs

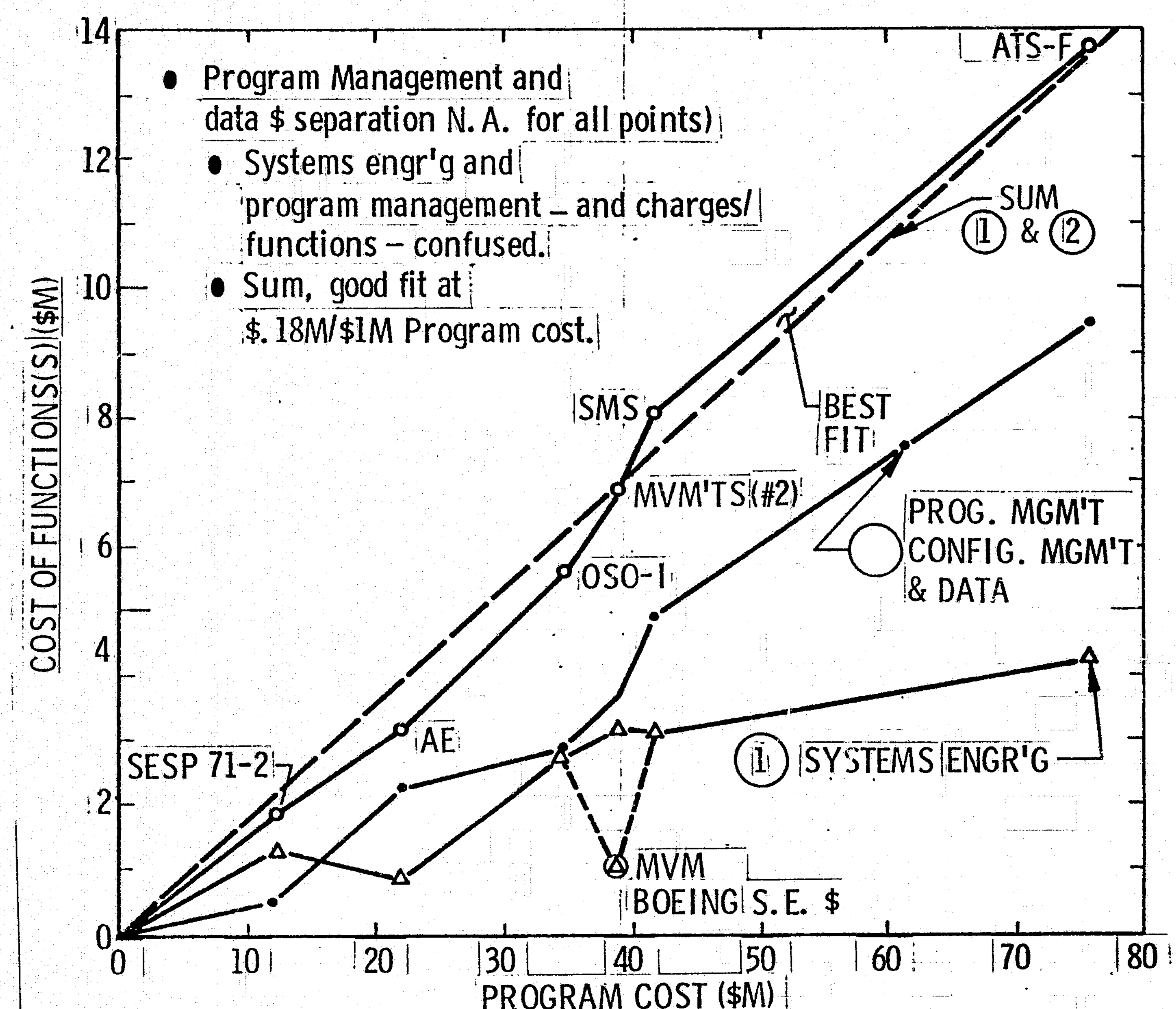


Fig. 6-11 Systems Engr'g Charges Vs. Program Cost

from program management costs, therefore these are shown combined in Fig. 6.11. Interestingly, the summed curve provides a fairly good fit for the six programs (MVM '73 is an estimated point). The systems engineering and the program management cost curves flip-flop supporting the contention that different programs charge some S.E. to program management or vice versa. Even Atmospheric Explorer is not very far out of line (as shown in Fig. 6-10) when its S.E. and program management costs are combined.

On the **average**, the sum of systems engineering, program management, configuration management and data represents 18% of spacecraft program cost. Configuration management and data costs are fairly consistent at about 2% leaving 16% for combined S.E. and program management efforts. From the standpoint of direct program manhours, 2 out of every 10 manhours (20%) are spent on the combined functions of systems engineering, program management, configuration management and data.

6 SE & I PRACTICES

Historical SE&I practices could neither be identified nor quantified during this study. Meaningful identification and quantification was precluded by incomplete and inconsistent practices in the areas of Program Definition, RFP and WBS preparation and record-keeping.

6.7 CONCLUSIONS

- It appears as if NASA is paying from 2.8 to 11.4% of each programs total cost for something called Systems Engineering (or sometimes called System Engineering and Integration) but the definition of that something is very vague and the associated cost accounting trails are most often even more vague.
- Very few, if any, meaningful PER's can be developed from the NASA and Air Force data IMSC has seen to date:

  No commonly accepted definition of SE&I function exist within NASA: Efforts requested in RFP's vary greatly.

  Charges for various SE&I functions usually are not recorded against each function performed due to mixed NASA WBS and contractor organization reporting structure.

- NASA's practices relative to structuring complete WBS's (with one and only one place to charge for each SE&I task) must be improved before accurate practice/cost evaluations can be made (based upon actuals).

- The need for various SE&I tasks vary greatly with each type of Program:

  New programs requiring State-of-the-art advancements

  New programs using only proven technologies

  Follow-on programs with High Inheritance (T&H)

  Follow-on programs with Low Inheritance (T&H)

  New programs with standardized components

  Follow-on programs incorporating standardized hardware.

- LMSC may not be able to develop PER's based exclusively on historical data even if complete historical data from 8 to 10 programs is made available, because:

  Cost records tend to be misleading and inaccurate

  Cost record to WBS levels 4, 5 and 6 are needed for this analysis but are normally reported to NASA at levels 1 and 2.

- Some PER's based upon a combination of historical data and engineering estimates may be feasible.

- Checklists for low-cost and high-cost SE&I practices, with supporting explanatory rationale and pertinent cost estimating parameters could be developed in lieu of quantified graphic PER's.

6.8 RECOMMENDATIONS

* • Discontinue this effort until more enlightening historical data can be made available.

- Develop a NASA-wide definition of SE&I functions to be performed on programs which eliminate or clarify overlaps with other functions such as subsystem engineering, management, configuration management and data management.

* • Develop a standardized WBS for charging SE&I charges in a manner which assures they are separated from other functions and in sufficient detail as to record variations of costs due to variations of SE&I practices from program to program.

• Include results of the above definition and WBS recommendations plus specific instructions for their use in future RFP's.

* This recommendation was made during the mid-term study review and were acted upon by NASA.

Lockheed Missiles & Space Company

LCPP-9

ENGINEERING MEMORANDUM

TITLE: GROUND SUPPORT EQUIPMENT (GSE) COST IMPACT ANALYSIS	EM NO: LCPP-9 REF: DATE: 1 May 1975
AUTHORS: J. B. Forsyth	APPROVAL: ENGINEERING SYSTEM ENGRG D L Hannsford

INTRODUCTION

Lockheed Missiles and Space Company is currently performing the Low-Cost Program Practices study for NASA Headquarters under contract number NAS W-2752. The principal objective of the study is to identify those NASA space program practices that contribute significantly to program costs. As part of this study an analysis of the cost impact of Ground Support Equipment (GSE) has been completed, and the results of the analysis are presented in this engineering memorandum (EM). The scope of the analysis was constrained by the limitations of the relevant data.

GROUND SUPPORT EQUIPMENT (GSE)

COST IMPACT ANALYSIS

9.1 BACKGROUND

The GSE (Ground Support Equipment) Cost Impact Analysis was one of the subtasks in the cost impact analysis area of investigations performed as a part of the Low-Cost Program Practices study. NASA interest in GSE costs has been of long standing, probably dating to the substantial outlays made in the Saturn/Apollo days. In this study, the GSE cost impact analysis was limited to unmanned automated spacecraft programs and the GSE practices being applied in that type of program.

9.2 OBJECTIVES AND APPROACH TO GSE COST IMPACT ANALYSIS

The objectives of this subtask were to define the approximate cost contribution of GSE to spacecraft programs, and to identify the cost impacting practices which lead to higher or lower GSE costs on a given unmanned spacecraft program.

The GSE considered in this analysis included all program-peculiar GSE used at all locations (contractor and subcontractor plants, NASA and/or contractor field sites, and launch base; up to and including launch). Also included was the government furnished equipment (GFE) GSE used on spacecraft programs. Post-launch support equipment used at launch site, tracking stations (data links), and data reduction centers were excluded.

Typical GSE categories pertinent to a space program are:

- o Test and checkout equipment
  - o Manufacturing test equipment
  - o Simulators

  - o Test support equipment (test chambers, fixtures)
  - o Integrated S/C and systems test equipment
- o Transportation and handling equipment
  - o Transporters, trailers, dollies
  - o Lifting gear, support fixtures, stands
  - o Shipping containers
- o Servicing equipment
  - o Expendables conditioning/loading/venting equipment
  - o Environmental conditioning/protection equipment
- o Launch control/monitoring equipment
  - o Consoles (launch processing equipment)
  - o Umbilicals/disconnects

The approach to this task was to collect historical GSE cost and programmatic data by researching past spacecraft programs and by sending out a GSE cost impact questionnaire directly to NASA centers and the spacecraft industry. An example of the questionnaire and a detailed discussion of the responses are included in the appendix. The collected data base was used in implementing the following GSE analysis tasks:

(1) Determine type, quantity, and usage (location, transfers, redundancies) of GSE on historical and current spacecraft programs.

(2) Tabulate historical costs of GSE, with breakdown into major categories (and for individual equipment items, where possible).

(3) Analyze the cost impact of specific practices (typically):

- o Use of commercially-available components
- o Specifications imposed (by customer and contractors)
- o Degree of standardization:
  - o Within a single program
  - o Among NASA centers

- o Use of common equipment for launch vehicle and payload
- o Scheduling of utilization forsame GSE item (geographical transfer vs redundancy)

(4) Estimate average cost reduction for alternate GSE low cost practices for:

a. Current unmanned space program hardware

b. Modularized future spacecraft with refurbishable/reusable equipment

9.3 TYPES OF AVAILABLE GSE DATA

The GSE data sources and their availability are indicated in Fig. 1. As revealed by this figure, the data base is sparse and incomplete with overall cost data available for nine programs, but with very limited cost detail.

The GSE questionnaire provided additional insight for six of the listed programs as to the GSE practices and cost breakdowns, however the questionnaire was not intended for detailed GSE description and cost collection. Some of the GSE description was obtained from GSE plans, such as on the HEAO program; and for other programs listed on Fig. 1 major GSE categories were extracted with their costs from studies done by program contractors for NASA.

Review of these available data pointed out the lack of commonality in GSE categories, descriptions, and grouping of costs. Fig. 2 lists the variable terminology used by programs in defining the GSE categories.

Also lacking was the description and quantification of existing or GFE GSE to be used by a program. The existing GSE could be substantial and is certainly variable from program to program. The GFE GSE contribution to a program also varies and its magnitude is significant in most cases. With these two major unknown variables affecting a given program's GSE, the data obtained were incomplete and difficult to analyze due to lack of common (normalized) starting point.

Program	Agency	Contractor	GSE Q Sent	GSE Q Answ.	Detail GSE List	Equip. Categ. Desc.	Genl. Desc.	GSE Plan	Cost Data O. A.	Cost Data Categories	Cost Data Funct.
ERTS	GSFC	GE	Y	N	N	N	N	N	N	N	N
Nimbus-G	GSFC	GE	Y	N	Y	N	N	N	N	N	N
OSO-1	GSFC	HAC	Y	Y	N	Y	Y	N	Y	Y	Y
HEAO-A, B, C	MSFC	TRW	Y	Y	Y	Y	Y	Y	Y	Y	Y
Pioneer-Ven.	Ames	HAC	Y	N	N	N	Y	N	N	N	N
Pioneer 10, 11	Ames	TRW	Y	Y	N	N	N	N	Y	Y	N
ATS-F	GSFC	Fairchild	N	N	(P)	(P)	N	N	Y	N	Y
AE	GSFC	RCA	Y	Y	(P)	N	Y	N	Y	Y	Y
MVM-73	JPL	Boeing	Y	N	Y	N	N	N	(P)	N	N
SMS	GSFC	Philco	Y	Y	Y	N	Y	N	Y	Y	Y
71-2	AF	LMSC	Y	N	Y	Y	Y	Y	Y	Y	Y
P-50	AF	LMSC	Y	Y					Y	Y	Y

Fig. 1 - GSE Data Sources and Availability

Definition	MVM 73	Pioneer-Venus	AE	SMS	OSO-I	Nimbus-G	HEAO-A, B	71-2	Apollo	SRM
Test & Support Equipment	X									
System Ops Support Equipment	X									
Subsystem Support Equipment	X									
Assy, Handling, & Shipping Equipment	X									
Ground Support Equipment		X								X
Handling & Shipping Equipment		X			X					
Systems Test AGE - Integrated Spacecraft								X		
Launch Complex AGE								X		
Ground Handling Equipment								X	X	
Systems Test AGE - Experiments								X		
Servicing Equipment									X	
Checkout Equipment									X	
Auxiliary GSE									X	

Fig 2(a) - GSE Definitions Used on Programs (1 of 2)

Definition	MVM 73	Pioneer-Venus	AE	SMS	OSO-I	Nimbus-G	HEAO-A, B	71-2	Apollo	SRM
Transportation Support Equipment										X
Special Test Equipment										X
Mechanical AGE/BTE				X						
Electrical AGE/BTE				X						
Systems Test Equipment					X					
Experiment Simulator					X					
Integration Test Equipment					X					
Cleanliness Equipment					X					
Mechanical Support Equipment						X	X			
Electrical Support Equipment						X	X			
Chamber Equipment						X				
Aerospace Ground Equipment			X							
Experiment Support Equipment							X			
Factory Support Equipment							X			

Fig 2(b) - GSE Definitions Used on Programs (2 of 2)

Therefore, most of the limited GSE analysis was done with the data extracted from the GSE questionnaire and supplemented by other data on an as-available basis.

9.4 GSE QUESTIONNAIRE

The GSE questionnaire responses were obtained from one NASA center and six spacecraft program contractors representing six different programs (five NASA, one AF).

The highlights of the GSE questionnaire results are discussed below.

Based on nine spacecraft programs, the contractor-supplied GSE averages 4.7% of total program cost. The questionnaire results (6 programs) indicated the same percentage, although the detailed responses (4 programs) showed contractor supplied GSE at 5.3% of total program cost.

In terms of major GSE categories, the breakdown shown in Fig. 3 was derived. The contractor supplied GSE percentages are based on six spacecraft programs and the GFE GSE percentages are from five programs. In terms of GSE cost, the test and checkout equipment is the major GSE category, contributing 80 to almost 100 percent of contractor supplied and GFE GSE costs respectively.

Utilizing absolute GSE costs for four spacecraft programs (1971/73 $) and the above average percentages, the GSE costs by major cost category were extrapolated as shown in Fig. 4. This sample indicates that a contractor supplies 84% of GSE and 16% is GFE on a spacecraft program. This breakdown does not consider the existing GSE in contractors' possession (sunk costs), only the new GSE charged to the program or new GFE GSE. Also GSE capitalized by the contractor is not included.

The breakdown for new vs modified GSE costs indicates that about 90% of GSE cost is spent on new GSE. The usage of surplus GSE from another program is

MAJOR GSE CATEGORY	Contractor Supplied GSE			GFE GSE	
	% Range	Ave. %	% of TPC *	% Range	Ave. %
HANDLING & TRANSPORT EQUIP.	5-20	12.6	0.6	0-5	2.0
SERVICING EQUIPMENT	0-20	7.6	0.4	0-10	2.0
TEST & CHECKOUT EQUIPMENT (INCL. LAUNCH CONTROL EQUIP.)	70-94	79.8	3.7	90-100	96.0
TOTAL		100.0%	4.7%		100.0%

* TPC = Total Program Cost

Fig. 3 - Major GSE Category Costs (Percent)

MAJOR CATEGORY	Contractor GSE		GFE GSE		Total GSE Cost	
	%	Extrap. $ M	%	Extrap. $ M	$	Extrap. $M
HANDLING & TRANSPORT EQ.	12.6	0.33	2.0	0.01	11.0	0.34
SERVICING EQ.	7.6	0.20	2.0	0.01	6.8	0.21
TEST & CHECKOUT EQ.	79.8	2.07	96.0	0.48	82.2	2.55
TOTAL	100.0%	$2.60M	100.0%	$0.50M	100.0%	$3.10M
PERCENT OF TOTAL PROGRAM COST		5.3%		1.0%		
SHARE OF TOTAL GSE		84%		16%		100%

* Based on four spacecraft programs. Excludes all contractor and GFE GSE costs which are sunk or capitalized by contractor.

Fig. 4 – Average GSE Costs Extrapolated by Major Category *

limited. Most of the contractor supplied GSE on a program (over 80% in terms of cost) is used both at the contractor plant and at the launch base. The GFE GSE is primarly used at the launch base only (60% in terms of GFE GSE cost).

The contractor supplied GSE costs, based on responses from five programs, are broken down functionally as shown in Fig. 5.

For additional GSE questionnaire responses and their analysis see the Appendix.

9.5 COMPARATIVE COSTS OF GSE

The tabulation of contractor supplied GSE costs as charged to the program is presented on Fig. 6. Also tabulated for each program is the percentage of total program cost represented by this GSE. This percentage ranges from a high of 8.6% to a low of 3.1%.

For some programs further GSE cost breakdown was obtained as actuals incurred on a program or as estimates. Fig. 7 is the breakdown of OSO-I GSE costs as charged to the program, excluding GSE paid for by the contractor and GFE GSE. These costs represent one set of GSE.

The HEAO GSE costs were extrapolated from manhour estimates prepared by the contractor and are shown in Fig. 8. These costs represent one set of GSE as estimated for the HEAO program program.

Similar detail was not available on other programs, but a GSE cost summary by major GSE category was derived for six spacecraft programs as shown in comparable 1975 $ in Fig. 9. Then the costs were allocated by reported percentages to the functional cost categories as shown in the lower half of Fig. 9.

Figure 5

Contractor GSE Cost Breakdown

(Percent)

	% Range	Ave. %
Planning and Requirements	3-5	4.4
Design Engineering and Development	10-40	22.8
Sustaining Engineering	0-5	1.4
Procurement/Purchase/Lease	10-50	32.6
Manufacture of New GSE	10-30	16.5
Modification of Existing GSE	3-5	4.3
Qualification testing	0-5	1.0
Acceptance testing	0-5	1.4
Installation and Checkout	0-5	2.2
Maintenance	0-10	3.2
Documentation	5-20	10.2
Total GSE		100.0%

Source: GSE questionnaire, 5 S/C programs.

Spacecraft Program	Cognizant Agency	S/C Contract	GSE Cost M of $	Total Program Cost M of $	Av. Year Expend.	GSE (3) % of T. P. C.
OSO-1	GSFC	Hughes	$1.05 (1)	34.281	71/72	3.1%
ATS-F	GSFC	Fairchild	10.1 (4)	110.3 (4)	71/72	7.7% (4)
SMS	GSFC	Philco	1.985 (5)	44.2 (5)	71/72	4.5% (5)
AE	GSFC	RCA	.729	21.761	72/73	3.3%
MVM-73 (Part 2)	JPL	Boeing	2.067 (2)	38.597	71/72	5.4% (2)
71-2	AF	LMSC	.921	12.026	70/71	7.6%
Pioneer F&G	AMES	TRW	4.3	50.0	70/73	8.6%
HEAO	MSFC	TRW	2.5 Est.	80.0 Est.	74/77	3.1%

(1) Excluding test equipment for experiments
(2) Excluding some subsystem support equipment and system test equipment
(3) Spacecraft contractor program
(E) Estimated
(4) Excluding systems test complex
(5) Excluding tracking station equipment (≈ $810K)

Fig. 6 - Comparative Costs of Contractor Supplied GSE (as charged to the program)

Figure 7

OSO-I GSE Costs

(1 set, actual costs)

	Actual Costs ($M)		1975 ($M)
o Test & c/o equipment:	$ .705M		$ .875M
System Test Equipment	$ .439M		$ .545M
Command Encoder PCM Decommutators (2) General Test Equipment RF Measurement Equipment Power Equipment Mobile Test Stand (Pwr & Control Servicing)			
Experiment Simulator	.211		.262
System Test Cleanliness Equipment	.042		.052
Test Aids & Aux. Test Equipment	.013		.016
o Servicing Equipment	$.101M		$.125M
(Observatory TV Fixture Commercial Solar Simulator)			
o Handling and Transportation Equip.	$ .196M		$.244M
(Covers, guards, storage & shipping containers)			
o Technical Manuals & Documentation	$.048M		$.060M
Total Contractor GSE * (as charged to program)	$1.050M	(3.1% TPC)	$1.304M

Above costs in basic categories:

	Actual Costs ($M)	1975 ($M)
o Test & c/o eq.	$.735M	$.913M
o Servicing eq.	.105	.130
o Handling & transp. eq.	.210	.261
	$1.050M	$1.304M

* Excl. GSE paid for by Hughes & GFE Sigma 5 computers.

LOCKHEED MISSILES & SPACE COMPANY, INC.

HEAO GSE COSTS (Est. '75 $)

(1 set, costs based on manhour allocations and total dollar estimates)

o Integrated C/O Station (ESE)			$1.750 M
Management	.175M		
Engineering	.075		
System Test	.100	.350 M	
Power/Ordnance Console		.270	
ACDS Test Console/RCS Control & Monitor Unit		.290	
Telemetry & Command Console		.080	
RF Console		.240	
ADPE Console		.200	
Simulators		.185	
Aux. & Launch Supt Equip.		.070	
Spares		.065	
o Mechanical Support Equip. (MSE)			$0.750 M
10 Fixtures		$.408 M	
3 Slings/Hoists		.054	
4 Sets		.094	
2 Dollies		.041	
1 Container		.055	
MSE Mgm't & Admin.		.098	
Total Contractor GSE (as charged to program)			$ 2.50 M (3.1% TPC)

Above costs broken down into basic categories:

o	Test and c/o equipment	$1.750 M
o	Servicing equipment	.250
o	Handling & transport	.500
	Total *	$2.500 M

* Additional GSE paid for by contractor.

Figure 8

Category:	HEAO	OSO-I	SMS-A, B, C	AE-C, D, E	Pioneer F & G	SESP 71-2
Test & C/O Equip.	$1.750	$.913	$2.257	$.680	$5.077	$1.044
Servicing Equip.	.250	.130	-	.045	.169	.167
Handl. & Transp. Eq.	.500	.261	.209	.181	.395	.064
Total Contract GSE	$2.500	$1.304	$2.466	$0.906	$5.641	$1.275
% of TPC	3.1	3.1	4.5	3.3	8.6	7.6
No. of GSE Sets	1	1	2	1	2.5	1
Work Function:						
Planning & Requirements	$.100	$.065	$.104	$.045	N/A	N/A
Engineering & Development	.875	.588	.728	.091		
Proc./Purch./Lease	.975	.130	.383	.453		
Test	-	.065	.174	-		
Manufacturing		.261	.624	.135		
Inst. & C/O	.400	.065	.070	-		
Maintenance		.065	.035	.091		
Documentation	.150	.065	.348	.091		
Total Contr. GSE	*$2.500	$1.304	$2.466	$0.906	$5.641	$1.275

* Excl. all Post-Launch Equipment (i.e., Tracking Stations)

Contractor Supplied GSE Cost Breakdown by Major Equipment Category and Work Function (Est. 1975 $M)

Figure 9

9.6 GSE PROGRAM PRACTICES

9.6.1 Historical and Low Cost Practices

From the analysis of the available GSE data it appears that total program GSE cost consists of five types:

1) Contractor supplied GSE cost as charged to the program
2) Contractor supplied GSE capitalized by the contractor and not charged to the program (may or may not be sunk cost)
3) New or modified GFE GSE supplied at no cost to the program, but at cost to the government
4) Existing GFE GSE already in contractors possession (sunk cost)
5) Surplus GSE (may or may not be GFE and its replacement value represents sunk cost)

The contractor supplied GSE which is charged to the program has the most cost information available as compared to the other four GSE cost types. However even these cost data are aggregated by different contractors in different groupings (lack of commonality of definition) resulting in a difficult cost data retrieval problem.

The other types of cost are very rarely known or reported and therefore cloud the total GSE analysis problem by obscuring a common point of departure from which the analysis has to proceed. On a given program it is not known how much GSE sunk cost has been applied in addition to the known contractor supplied GSE charged to the program.

Based on very rough order of magnitude (ROM) estimates for six spacecraft programs the following highly subjective average percentages for GSE costs by type were derived:

1)	Contractor supplied GSE charged to program	44%
2)	Contractor supplied GSE not charged to program	16%
3)	GFE GSE new or modified	9%
4)	GFE GSE sunk cost	30%
5)	Surplus GSE at replacement value	1%
	Total ROM GSE Cost (excl. post-launch GSE)	100%

Therefore it appears that for a given spacecraft program less than half of total (as defined above) GSE value is charged to the program. These programs were of the early 1970's vintage performed by mature aerospace industry with extensive GSE inheritance.

The above illustrates the basic practice, both historical and low cost, of extensive GSE inheritance being applied to current spacecraft programs resulting in contractor supplied GSE as charged to the program averaging at 4.7% of total program cost.

Another historical and low cost practice implemented by half of the programs responding to the questionnaire was little use of GSE redundancy. Some redundancy of handling equipment, which is relatively low cost GSE, was reported.

Cycling of GSE from factory to launch base has been practiced historically on most spacecraft programs. Also required by most RFPs has been the maximum usage of existing GSE. The responding programs indicate that the existing GSE, if available, could be used with little or no maintenance.

Most programs build GSE to project peculiar specifications and some to commercial/industrial specifications. These are less severe than government GSE specifications, which were applied to less than half of the spacecraft programs analyzed. A minimum GSE cost objective has been stated in 2/3 of the program RFPs.

9.6.2 Historical and High Cost Practices

An historical and high cost practice reported by most programs, which impacts GSE cost, is the change in GSE requirements primarily due to changes in the spacecraft, and some due to program plan and experiment changes. Apparently most programs do not make provisions in GSE for S/C growth, multiple uses, or further uses.

Another high cost GSE practice applied by some S/C programs is formal acceptance testing of GSE. Some programs indicated no GSE testing other than inspection, which appears to be a cost effective practice.

With respect to "existing" GSE (interpreted by responders as other existing GSE not in their possession): little use is made of such GSE except in the case of predecessor/follow-on space programs. This is due to the fact that little existing GSE design or cost information is available. Half of the responders indicated that no data or hardware was "available" on "existing" GSE. Lack of common GSE terminology/definition contributes to this problem, and one third of the responders indicated that they do not keep a consolidated GSE inventory list. Almost all responders said that the contractors and the government (in case of GFE items) have no cost values recorded for individual GSE items.

A major hindering practice to multiple program use of "existing" GSE, in addition to lack of information discussed above, is the fact that 98% of GSE value is retained and stored at the contractor plant at the end of contract - 58% has follow-on usage and 40% no further identified use as reported by responders to the GSE questionnaire. (Also reported by responders was the fact that 73% of contractor supplied GSE cost is for non-deliverable GSE).

Above points indicate little multi-usage of GSE within an agency and minimum interagency sharing, although individual contractors make maximum use of existing GSE in their possession.

9.7 CONCLUSIONS AND RECOMMENDATIONS

From the analysis of limited GSE data, primarily results of the GSE survey questionnaire consisting of six spacecraft programs, it appears that there is a trend towards low cost practices in the GSE area. The maximum use of existing GSE in contractors' possession, application of non-government specifications to new GSE, reduced or eliminated GSE testing, and non-redundancy of GSE items all point in the direction of minimizing GSE costs.

Potentially significant additional GSE cost reductions could be obtained by increased use of industry/agency-wide existing GSE if more information were to be disseminated about if - both detailed design and GSE status/cost data. NASA is currently in process of computing an inventory of existing GSE called EVS (Equipment Visibility System) which is to be computerized and possibly available to all NASA agencies, as well as contractors in the near future. Future RFPs should call out the use of this GSE inventory and require cost-tradeoffs in cases of deviations. Another requirement in design of new GSE should be that it be multi-use, tending towards standardization, and incorporate allowance for growth of spacecraft.

The additional estimated savings from maximum use of existing GSE under the above multi-use GSE inventory plan can be expected to reduce the GSE costs to about one half of the current average costs. This statement is based on comparing the contractor supplied Atmospheric Explorer GSE costs (low cost program with maximum use of existing GSE and all commercial specifications on new GSE) to average GSE cost of the other spacecraft programs.

The GSE cost comparison shown in Fig. 9., broken down functionally, indicates that the Atmospheric Explorer had lower GSE planning and requirements costs, lower documentation costs and no GSE testing costs. Converting these savings into percentages and applying them to the average costs incurred on the other three spacecraft shown provides the following GSE savings estimates in three areas:

o	Planning and Requirements savings	47%
o	Documentation savings	50%
o	Test savings	100%

The above three areas combined result in average GSE savings on the three spacecraft programs of about 10%, ranging from 5% to 16%, for the contractor supplied GSE costs charged to the program. These savings can be implemented now before the existing multi-use GSE inventory becomes a reality and provides the significant GSE cost savings discussed above.

GROUND SUPPORT EQUIPMENT

COST IMPACT ANALYSIS

APPENDIX

GSE QUESTIONNAIRE RESPONSES AND SAMPLE QUESTIONNAIRE

GSE QUESTIONNAIRE RESPONSES

Seven responses were received to the GSE Cost Impact Questionnaire sent out to spacecraft contractors and NASA centers. The following discussion summarizes the answers received encompassing six spacecraft-programs of the 1970's. The summary of the responses follows the sequence and identification numbers of the questions in the questionnaire. In some cases there are minor discrepancies in the average quantified responses. These are due to change in sample size, since not all of the questions were answered by all the responders.

GSE QUESTIONNAIRE RESPONSE SUMMARY

1.0 Program characteristics

1.1 Timing of the 6 spacecraft (S/C) programs was:

- o 1970-74 Program starts
- o 16 months average till S/C design freeze
- o 38 months average till first flight
- o 4.3 months average after S/C design freeze, final GSE design release
- o 8 months average for GSE manufacturing and procurement

1.2 Considerable S/C technology inheritance on all 6 programs was indicated; active subsystems were similar to previous programs and three programs had similar structure.

1.3 Ground support plans or philosophy on the responding programs were essentially the same as on previous programs for 67% ; 33% had basically different plans.

1.4 Number of equivalent spacecraft to be supported by GSE ranged from 1.5 to 7.0; average 3.5.

1.5 Multiple flight programs had the same spacecraft hardware, and the experiments were the same for the majority of programs.

1.6 The complexity of S/C and experiments relative to GSE requirements was moderate to complex for both spacecraft and experiments.

1.7 Omitted

1.8 Integration and testing of program hardware was performed on:

a) spacecraft - 100% by S/C contractor
b) experiment and spacecraft integration - 83% by S/C contractor - 17% by associate contractor
c) Integrated S/C with launch vehicle and facilities - 100% by S/C contractor with 33% of the programs indicating customer support.

1.9 Program integration was performed at the spacecraft contractors plant, with one program indicating experiment/spacecraft integration taking place at the launch base.

2.0 GSE plans and requirements

2.1 GSE plan was developed by 83% of the contractors as a part of their proposal. On one program (17%) the customer prepared the GSE plan prior to RFP release.

2.2 On all NASA programs, the GSE plan included both contractor and GFE items.

2.3 GSE functional requirements were prepared as follows:

	Experiment Contractor	S/C Contractor Only	Customer Only	S/C Contractor & Customer
For S/C	-	67%	-	33%
For Experiments	17%	33%	50%	-
For Integrated S/C	-	83%	-	17%
Average	5%	61%	17%	17%

- o S/C contractor prepared most of the GSE functional requirements in all areas except experiments.

2.4 GFE (government furnished equipment) GSE was identified by:

	Contractor	Customer
o In RFP	-	33% programs
o In contractor proposal	50%	-
o In previous contract	-	17%

2.5 GSE for mission equipment was supplied by:

- o Customer only on 33% programs
- o Experiment associate contractor,33% programs
- o Customer and exp. associate contractor, 17% programs
- o Spacecraft contractor and exp. associate contractor, 17% programs

2.6 After contract go-ahead, cost impacting changes in GSE requirements and their degree were:

	None	Moderate	High
o Change in total program plan	1	3	1
o Change in spacecraft		3	2
o Changes in experiments		3	
o Schedule and funding			1

2.7 Contract End Item (CEI) Part 1 Design-to specs were required and prepared only for a portion of GSE and

2.8 CEI Part 2 specs were not required on any of the programs responding.

3.0 GSE quantity influences:

3.1 Redundant quantities of GSE items were required on 50% of the programs.

3.2 The 50% of programs requiring redundant GSE sets indicated the following average redundant GSE distribution:

o Handling equipment	2.3 sets
o Shipping containers	1.0
o Servicing equipment	1.7
o Environmental control equip.	0.7
o Interface simulators	1.7
o Test equipment	1.3

3.3 In all cases the program schedule allowed moving and cycling of GSE items among factory, integration facility, and launch base.

3.4 Complete integration of spacecraft and experiments was accomplished at the spacecraft contractors' factory on all NASA programs. In case of the AF programs, 80% of this integration was accomplished at the launch base and only 20% at the spacecraft contractor's factory. Integration contractors and separate government facilities were not used by the responding programs.

4.0 General specification requirements for GSE

4.1 The general specifications/requirements applied to GSE design, manufacturing, and testing were primarily commercial/industrial and project peculiar specs - average 59% of the GSE dollars. Government specs were applied to an average of 41% of the GSE dollars.

4.2 The operating environmental requirements imposed on the GSE were the same for the factory and launch base GSE. 66% of the programs indicated imposition of project-peculiar specs, with one program (17%) complying with only general commercial specs, and one (17%) program complying only with government aircraft and ground equipment specs (MIL-E-5400 or MIL-E-16400).

4.3 Project peculiar specs had less severe requirements than MIL specs, as reported by 80% of the programs using project peculiar specs. One program thought the requirements to be the same, and one program indicated that depending on the GSE item the severity of the requirements varied.

4.4 The responses to the question: "What type/degree of testing was applied to GSE?" By GSE category, were distributed as follows:

	Qual Test	Formal Accept Test	Mfg. Insp & Test
o Ground Handling & Transp. Equip.	1	4	2
o Ground Servicing Equip.	1	3	2
o Launch Base Equip.	1	4	1
o Factory Support Equip.	-	3	4
o Other - Electrical c/o Equip.	-	-	1

The above indicates predominance of formal acceptance testing in all GSE categories except for the factory support equipment.

4.5 On GSE supplied as contract GFE, testing was performed by contractor only on 66% of the programs; by customer only on 17% of the programs; and by both contractor and customer on 17 % of the programs. Of the programs where contractor only did the GFE-GSE testing, all items were tested on 75% of the programs, and on 25% of the programs only some items were tested.

4.6 Maximum use of existing GSE was specified in all responding program RFP/ contract requirements/specs.

4.7 All responding programs made a specific review of spacecraft requirements and their impact on GSE complexity, compatibility, and cost.

4.8 The response distribution to the question, "Were provisions required in the GSE to anticipate the following," was:

	Yes	No
o Specific application to later spacecraft of the same or similar program series	5	2
o Spacecraft growth (size, weight, performance)	1 (some)	6
o General application to similar spacecraft in other programs	1 (some)	6

The above responses indicate that GSE is tailored for a specific application/ program without much consideration for further uses.

4.9 The GSE performance requirements include primarily a moderate contingency allowance as indicated by 50% of the programs. 33% of the programs indicated a small contingency allowance, and one program said that the contingency allowance varied depending on the particular piece of equipment.

4.10 The responses to the question "For what levels of testing was GSE required?" were distributed as follows:

o Component	3
o Black Box or Assembly	4
o Subsystem	4
o Spaceframe	2
o Spacecraft	7
o Experiments	4
o Integrated Spacecraft	7

5.0 <u>Commonality of GSE</u>

5.1 The investigations of existing GSE designs and/or equipment for possible application were made as follows on the 6 programs:

	By Contractor	By Customer	Both
o Before RFP release	-	1	1
o Prior to contractor proposal	6	-	-
o After contract go-ahead	2	-	2

5.2 The existing GSE data sources used and selected items were (in terms of number of programs):

	Source Used	Item(s) Selected
o MIL-H BK-300, Tech. Info. File on GSE	-	-
o Predecessor Program GSE Plans/ Lists	6	4
o Same Agency GSE Inventory List	3	-
o Other Agencies GSE Inventory List	1	-
o NASA-wide List of Space Program GSE	1	-
o AF List of Space Program GSE	1	-
o General Services Admin. Surplus Lists	2	-
o Defense Industry Production Equip. Catalog (DIPEC)	1	1
o Commercial/Industrial Applicable Equip.	4	1

The above answers indicate that most of the responding programs surveyed commercial/industrial applicable equipment and all programs reviewed the predecessor program GSE. Most of the programs selected GSE items from the predecessor program plans/lists.

5.3 Only two programs (33%) indicated that the existing GSE lists they reviewed contained GSE item costs. Others indicated no, or partial, GSE cost information.

5.4 All responders indicated that they reviewed the lists of existing GSE for space programs only. They did not look for potential common GSE equipment from other areas (i.e., aircraft, missiles, launch vehicles, etc.).

5.5 The status of "existing" GSE with potential application to their program was described by the four responding programs (in terms of number of programs responding) as:

	Available	Unavailable
o Outline Descriptions	3	-
o Design/Performance Spec. Sheet	1	-
o Detail Design Data	2	-
o "Surplus"Equipment	2 (some)	1

Three programs (50%) responded that no data/hardware was available on "existing" GSE.

5.6 The usability status for "existing" GSE items was:

o Ready for use immediately	22%
o Required simple maintenance	44%
o Required major overhaul	22%
o Not available because of schedule conflict	12%

5.7 Actual usage of some GSE from another program was made by 67% of the programs (33% had no usage):

1 program used $20K in terms of replacement value (4 items)
1 program used $60K in terms of replacement value (4 items)
1 program used $123K in terms of replacement value (12 items)
1 program used minor cost items, value and quantity not indicated.

5.8 To the question "Does your Agency/Company keep an updated inventory list for spacecraft program GSE items?" response was as follows:

o	Consolidated-total aerospace community (NASA/DOD/ Industry)List	17%
o	Consolidated-Agency only list	17%
o	Consolidated - for single program series, list	17%
o	No "consolidated" list	33%
o	Don't know	16%

5.9 After completion of a program the GSE is disposed of as follows (No. of responders):

			Yes	No
o	"Advertised" as available		4	-
	- within agency	2		
	- within DOD	2		
	- within NASA	3		
	- to GSA	2		
	- other (agency decision)	1		
o	Stored under maintenance		2	2
o	Stored without maintenance		4	-
o	Scrapped (eventually)		4	-
o	Other - disposed of in accordance with ASPR (NASA) 24		1	

From the above responses, the majority said that after completion of a program GSE is "advertised" while stored without maintenance, and then eventually scrapped.

5.10 All programs responded that the GSE design requirement for common usage at both factory and launch base was considered and actually implemented on most or all items. 83% of the programs traded off that requirement in cost-effectiveness terms.

5.11 To the question: "How long (average) is GSE held by a program before disposal," most responders had no specific answer. One program felt that it was determined by the agency. One program indicated 18 months as the average time GSE is held by a program before advertising and 18 months before scrappage.

5.12 86% of the responders to the question: "Is there any policy or procedure for interchange of GSE items between NASA centers or NASA and AF", said they did not know. One responder (14%) felt there was a GSE interchange policy or procedure between NASA centers.

5.13 All responders said that lack of common "definitions" for GSE items causes a problem in identifying multiple usage or considering commonality. One responder felt it was a minor problem.

5.14 The responses to the standard format GSE catalog desireability question were divided:

57% said it should be established (possibly only for GSE which is available or will be available soon)

14% said it should not be established (it would not be cost effective)

29% had no opinion

6.0 <u>Definitions and costs of GSE elements</u>

6.1 The GSE categories used by 5 programs and the percentage of contractor-supplied GSE cost attributable to each category are tabulated below:

	PROGRAMS				
	A	B	C	D	E
Ground Handling Eq.			19%	6%	2%
Transport Suppt. Eq.				4%	
Grd. Servicing Eq.				1%	20%
Mechanical Supt. Eq.	30%	6%	-	10%	-
Electrical Supt Eq.	70%	65%	-	-	-
Test & Supt Eq.	-	-	10%	-	-
System Test Eq.	-	-	41%	20%	35%
Special Test Eq.	-	-	-	4%	-
Test Aids & Aux. Test Eq.	-	-	1%	-	-
Bench Test Eq.	-	-	-	10%	-
S/S Complete Test Eq.	-	-	-	10%	-
Factory Test Equip.	-	-	-	35%	-
Launch Complex Eq.	-	-	-	-	43%
Other Categories (4)	-	29%	29%	-	-
Total	100%	100%	100%	100%	100%

6.2 On the average, the contractor supplied GSE cost is attributable primarily to test and checkout equipment (including launch control equipment). It constitutes 80% of the GSE cost. Handling and transportation accounts for 13% and servicing equipment for 7% of GSE cost. One responder indicated that 5% of the total contractor supplied GSE cost is due to manuals and training.

6.3 Follows 6.4.

6.4 Based on responses from 5 programs, the GFE GSE cost is almost entirely attributable to test and checkout equipment (ave. 96% of GFE GSE) and the remaining 4% is equally divided between the handling and transportation category and the servicing equipment category.

6.3 and 6.5

The relative usage of contractor supplied GSE (question 6.3) and GFE GSE (question 6.5) was responded to by 5 and 3 programs, respectively.

The following tabulation presents the summarized responses:

- o Ave. usage of contractor GSE (percent of each contractor GSE category, 5 S/C programs)

	Contractor Plant Only	Launch Base only	Both Plant & L. B.	Total
Handling & Transp. Eq.	0.8%	8.0%	91.2%	100
Servicing Eq.	7.5%	16.2%	76.3%	100
Test & C/O eq.	12.9%	12.0%	76.0%	100
Total Usage	6.8%	12.1%	81.1%	100

o Contractor GSE was moved and over 80% of it was used both places.

- o Ave. usage of GFE GSE (percent of each GFE GSE category) (3 S/C programs)

	Contractor Plant only	Launch Base only	Both Plant & L. B.	Total
Handling & Transp. Eq.	0	0	0	0
Servicing Eq.	0	100.0%	0	100.0%
Test & C/O Eq.	46.7%	20.0%	33.3%	100.0%
Total Usage	23.3%	60.0%	16.7%	100.0%

o GFE GSE was primarily used at Launch Base; there was less GFE GSE movement.

6.6 The responses by 5 NASA spacecraft programs were averaged to provide the following tabulation of average percent cost of new vs. modified GSE:

Major GSE Categories	Contractor GSE		GFE GSE		
	New	Mod	New	Mod	Total
Handling & Transport Eq.	87%	-	10%	3%	100
Servicing Eq.	100%	-	-	-	100
Test & C/O Eq.	59%	18%	15%	8%	100
Ave. Total	82%	6%	8%	4%	100

In summary:

- o New GSE represents 90% of GSE cost
- o Mod GSE represents 10% of GSE cost
- o Contractor GSE represents 88% of cost
- o GFE GSE represents 12% of cost
- o Contractor GSE is primarily new; servicing equipment is all new.

6.7 Based on 6 programs, the contractor supplied deliverable GSE represented 27% of GSE cost and the non-deliverable contractor supplied GSE accounted for 73%, on the average.

6.8 Based on answers from 3 NASA programs, the GFE GSE in contractors' possession represented 73% of the GSE and additional GFE GSE accounted for 25% of total program GFE, on the average.

6.9 Minimum GSE cost was identified as an objective in the RFP on 67% of the programs, 33% had no such objective stated.

6.10 Actual low-cost for contractor-supplied GSE was achieved by 83% of the programs and for GFE GSE by 50% of the programs.

Based on the 6 responding programs, the GSE cost represented on the average 4.7% of total program cost. The range of GSE cost was from 2% to 9% of total program cost.

6.11 To this question only 4 spacecraft programs provided a fairly complete answer. Based on this small sample, the average costs are:

o Average spacecraft contractor programs cost is	\$49.1M
o Average contractor supplied GSE cost is	\$ 2.6M
o Average government supplied GSE cost is	\$ 0.5M

6.12 The disposition of GSE from contractors' plants at the end of contracts was accomplished in the following manner (% of GSE value):

	Contractor Supplied GSE	GFE GSE	Combined Ave.
o Retained at contractors' plants for follow-on usage	63%	50%	58%
o Stored at contractors' plants (no further usage identified)	33%	50%	40%
o Shipped to government facility	4%	-	2%
Total	100%	100%	100%

The sum of the first two categories indicates that 98% of the GSE is retained and stored at contractors' plants.

6.13 Only one program out of the 6 provided contractor-supplied GSE to support new facilities. The portion of contractor-supplied GSE used for these purposes on this particular program was 4%.

6.14 Based on responses from 5 programs, the following tabulation shows the contractor GSE cost breakdown:

	% Range	Ave. %
Planning and Requirements	3-5	4.4
Design Engineering & Development	10-40	22.8
Sustaining Engineering	0-5	1.4
Procurement/purchase/lease	10-50	32.6
Manufacture of new GSE	10-30	16.5
Modification of existing GSE	3-5	4.3
Qualification testing	0-5	1.0
Acceptance testing	0-5	1.4
Installation and checkout	0-5	2.2
Maintenance	0-10	3.2
Documentation	5-20	10.2
Total contractor GSE		100.0%

6.15 The responding 6 programs did not include any costs associated with activities after launch, such as GSE sustaining engineering, except that two programs included GSE maintenance costs.

6.16 The answers to the question: "Is there a separate cost value recorded for each item of GSE on the total GSE list for contractor and GFE GSE?" were as follows:

	Yes	No
o Contractor-supplied GSE costs	1	6
o Government-furnished GSE costs	1	5

(SAMPLE)

QUESTIONNAIRE

GROUND SUPPORT EQUIPMENT (GSE)

COST IMPACT

Question Topics Covered

1. Program Characteristics
2. GSE Hardware Plans, Requirements
3. GSE Quantity Influences
4. General Specification Requirements for GSE
5. Commonality of GSE
6. Definitions and Costs of GSE

Note: For background, explanation, and instructions for questionnaire, see Attachment A. See Attachment B for Definitions.

GSE QUESTIONNAIRE

Program Data:

Program Name: ____________________

Cognizant Agency: ____________________

System Integrator: ____________________

Spacecraft Contractor: ____________________

Person Answering:

Date of Answer: ____________

Name: ____________________ Title: ____________

NASA Center or Company: ____________________ Division: ____________

Orgn. Name: ____________________ No: ________ Phone: ________

Mailing Address: ____________________

____

____

1. PROGRAM CHARACTERISTICS

1.1 What was the relative timing of spacecraft and GSE development and production?

a) Year (CY) hardware contract awarded? ________ ☐

b) Months from contract go-ahead to spacecraft design freeze? ☐

c) Months from contract award to first flight? ________ ☐

d) Months from spacecraft design freeze to final design release from GSE for manufacture or procurement? ________ ☐

e) Months for manufacture or procurement of GSE? ________ ☐

1.2 What was degree of spacecraft technology inheritance from previous program?

a) ☐ All new
b) ☐ Spacecraft similar; different mission equipment.
c) ☐ Subsystems similar
   ☐ Structure ☐ Elec. Power ☐ TT&C
   ☐ Attitude Control/Propulsion ☐ ________
d) ☐ None
e) ☐ (Other) ________

1.3 Was the overall ground support plan or philosophy (manufacturing/integration/test/launch) similar to an earlier program?

☐ Essentially same ☐ Similar
☐ Basically different ☐ ________

1.4 What were the quantities of equivalent spacecraft to be supported by GSE? (show quantity in each block)

a) Flight ______ ☐

b) Qualification ______ ☐

c) Protoflight ______ ☐

d) Spare Subsystem Sets ______ ☐

e) ______ ______ ☐

f) ______ ______ ☐

1.5 If program involved multiple flights, was hardware the same?

a) Spacecraft; ☐ Same ☐ Similar ☐ Different

b) Experiments; ☐ Same ☐ Different

1.6 Relative to GSE requirements, what was the degree of complexity of the spacecraft and the experiments?

a) Spacecraft; ☐ Simple ☐ Moderate ☐ Complex

b) Experiments: ☐ Simple ☐ Moderate ☐ Complex

1.8 Who performed integration and testing of program hardware?

	Customer Agency	Spacecraft Contractor	Separate Integrating Contractor(s)
a) Spacecraft (Spaceframe plus Subsystems)	☐	☐	☐
b) Experiments with Spacecraft	☐	☐	☐
c) Integrated Spacecraft with Launch Vehicle and Facilities	☐	☐	☐

1.9 Where was integration of program performed?

	Customer Agency	Spacecraft Contractor	Separate Integrating Contractor(s)	Launch Base
a) Spacecraft (Space-frame plus Subsystems)	☐	☐	☐	☐
b) Experiments with Spacecraft	☐	☐	☐	☐

2. GSE HARDWARE PLANS, REQTS.

2.1 Was a GSE Plan developed and when?

	By Contractor	By Customer
a) Before RFP release?		☐
b) As part of contractor proposal?	☐	
c) After contract go-ahead?	☐	☐
d) None	☐	☐
e) ______	☐	☐

2.2 Did the GSE Plan include both Contractor-furnished and GFE items?

☐ Yes ☐ No

2.3 By whom were initial GSE functional requirements prepared?

	By Contractor	By Customer
a) For Spacecraft	☐	☐
b) For Experiments	☐	☐
c) Integrated Spacecraft	☐	☐
d) ______	☐	☐

2.4 Was Government-furnished (GFE) GSE identified?

	By Contractor	By Customer
a) In RFP		☐
b) In Contractor Proposal	☐	
c) After contract go-ahead	☐	☐
d) None	☐	☐
e) ______	☐	☐

2.5 Who supplied GSE for Mission-Equipment?

- [ ] Customer
- [ ] Experiment Associate Contractor
- [ ] Spacecraft Contractor
- [ ] (Other) ______________________

2.6 Were the cost-significant changes in GSE requirements after contract go-ahead due to:

	Degree of GSE Cost Impact		
	None	Moderate	High
a) Change in total program plan	☐	☐	☐
b) Change in spacecraft	☐	☐	☐
c) Changes in experiments	☐	☐	☐
d) ______________	☐	☐	☐
e) ______________	☐	☐	☐

2.7 Were CEI (Contract End Item) Part 1 (Design-to) Specs prepared for GSE?

a) Before contract go-ahead? ______ ☐
b) During hardware acquisition? ______ ☐
c) Required for portion only of GSE ______ ☐
d) Not required ______ ☐
e) ______________ ☐

2.8 Were CEI Part 2 Specs required? ☐ Yes ☐ No

For approximately what % of total dollar value of GSE? ☐ %

3. GSE QUANTITY INFLUENCES

3.1 Were there concurrent activities which required redundant quantities of GSE items at factory, integration facility, and/or launch base?

☐ Yes ☐ No

3.2 Condition stated in 3.1 required how many total (duplicate) sets of equipment in following categories: (Enter total qty. of sets)

a) Handling Equipment ________ ☐

b) Shipping Containers ________ ☐

c) Servicing Equipment ________ ☐

d) Environmental Control Equipment ________ ☐

e) Interface Simulators ________ ☐

f) Test Equipment ________ ☐

g) ________ ☐

h) ________ ☐

3.3 Did the program schedule permit moving or cycling some items of GSE among factory, integration facility, or launch base (in lieu of providing multiple quantities)?

☐ Yes ☐ No

3.4 Was integration of spacecraft and experiments (or mission equipment) accomplished at: (Enter approx. % accomplished at each location)

a) Spacecraft Contractor Factory ________ ☐ %

b) Integration Contractor ________ ☐ %

c) Separate Government Facility ________ ☐ %

d) Launch Base ________ ☐ %

e) ________ ☐ %

Total 100 %

4. GENERAL SPECIFICATION REQUIREMENTS FOR GSE

4.1 What general purpose specifications or requirements were applied to GSE for design, manufacture, and testing? (Indicate by percentage of total dollars spent on GSE.)

a) ☐ Government Specs ________ ☐ %

b) ☐ Commercial/Industrial Specs ____ ☐ %

c) ☐ ____________________ ☐ %

d) ☐ ____________________ ☐ %

100%

4.2 What operating environmental requirements were imposed on the GSE?

	Factory GSE	Launch Base GSE
a) Aircraft and Ground Equipment Specs (MIL-E-5400 or MIL-E-16400) ________	☐	☐
b) General Commercial Specs ________	☐	☐
c) Project-Peculiar Specs ________	☐	☐
d) None ________	☐	☐
e) ________	☐	☐

4.3 If project-peculiar specs were applied to GSE, were they more or less severe requirements than the MIL specs?

☐ More ☐ Less ☐ Same

4.4 Which type/degree of testing was applied to GSE?

	Qual. Test	Formal Accept. Test	Mfg. Inspection
a) Ground Handling and Transport	☐	☐	☐
b) Ground Servicing	☐	☐	☐
c) Launch Base Equipment	☐	☐	☐
d) Factory Support Equipment	☐	☐	☐
e) (Other) ______	☐	☐	☐
f) (Other) ______	☐	☐	☐

4.5 Was testing performed on GSE supplied as contract GFE accomplished?

☐ By Contractor ☐ By Customer

☐ On some items ☐ On all items ☐ On None

4.6 Was maximum use of existing GSE specified in RFP/Contract requirements/specs?

☐ Required ☐ Suggested ☐ Not Specified

4.7 Was a specific review of spacecraft requirements and design made for impact on GSE complexity, compatibility with existing GSE, and cost of GSE?

☐ Yes ☐ No

☐ ______

4.8 Were provisions required in the GSE to anticipate:

	Yes	No
a) Application to later (modified) spacecraft of the same or similar program series?	☐	☐
b) Growth of spacecraft in terms of size, weight, performance?	☐	☐
c) General application to similar spacecraft in other programs?	☐	☐
d) ______	☐	☐

4.9 Did performance requirements for the GSE include:

a) Small contingency allowance? ☐
b) Moderate contingency allowance? ☐
c) Excessive contingency allowance? ☐
d) ____________________ ☐

4.10 For what levels of testing was GSE required?

a) ☐ Component
b) ☐ Black box or Assembly
c) ☐ Subsystem
d) ☐ Spaceframe
e) ☐ Spacecraft
f) ☐ Experiments
e) ☐ Integrated Spacecraft

5. COMMONALITY OF GSE

5.1 Were investigations made of existing GSE designs and/or equipment for possible application?

	By Contractor	By Customer
a) Before RFP release?		☐
b) Prior to contractor proposal?	☐	
c) After contract go-ahead?	☐	☐
d) ______	☐	☐

5.2 Which inventory lists, descriptions, data sources were used in determining potential applicability of existing GSE designs/ hardware to the new project? Were items selected from these sources for project usage?

	Source Used	Item(s) Selected
a) MIL-Hdbk-300, Tech. Info. File on GSE	☐	☐
b) Predecessor Program GSE Plans/Lists	☐	☐
c) Same Agency GSE Inventory List	☐	☐
d) Other Agencies GSE Inventory List	☐	☐
e) NASA-wide List of Space Program GSE	☐	☐
f) AF list of Space Program GSE	☐	☐

(5.2 continued on next page)

5.2 (Continued)

	Source Used	Item(s) Selected
g) General Services Admin. Surplus Lists ______	☐	☐
h) Defense Industry Production Equipment Catalog (DIPEC) ______	☐	☐
i) Commercial/Industrial Applicable Equipment ______	☐	☐
j) ______	☐	☐

5.3 Did the lists of existing GSE you reviewed contain approximate cost of each GSE item?

☐ Yes ☐ No

5.4 With regard to Question 5.2, were common inventory lists reviewed for potential GSE items in areas other than space programs?

a) Aircraft ☐

b) Ground/Air Weapons ☐

c) Missiles ☐

d) Launch Vehicles ☐

e) ______ ☐

5.5 If potential equipment usable for GSE were determined as "existing" on another program what was status of actual data/hardware availability for reuse on the current program?

	Available	Unavailable
a) Outline Descriptions ______	☐	☐
b) Design/Performance Spec Sheet ______	☐	☐
c) Detail Design Data ______	☐	☐
d) "Surplus" Equipment ______	☐	☐
e) Active Equipment - No Scheduled Usage ______	☐	☐
f) Active Equipment - Scheduled Usage ______	☐	☐
g) ______	☐	☐
h) ______	☐	☐

5.6 For "existing" GSE items, (See 5.5), what was the usability status?

a) Ready for use immediately.	☐
b) Required simple maintenance to "use" status.	☐
c) Required major overhaul.	☐
d) Not refurbishable.	☐
e) Not available because of schedule conflict.	☐
f) Unknown	☐

5.7 Was any major GSE item(s) from any other program actually used?

(Replacement cost; average cost per item)

Indicate Approximate Quantity of Items per each Cost Break	Yes	No	Item Replacement Cost
	☐	☐	$ 5000
	☐	☐	$ 5000 - 10000
	☐	☐	$ 10000 - 20000
	☐	☐	$ 20000 or more

5.8 Does your Agency/Company keep an updated inventory list for spacecraft program GSE items?

a) Consolidated - Total aerospace Community. (NASA/DoD/Industry) ☐

b) Consolidated NASA (or DoD) only. ☐

c) Consolidated - Agency only. ☐

d) Consolidated - For single program series. ☐

e) No "consolidated" list. ☐

f) ______________________ ☐

5.9 How is GSE disposed of after completion of a program?

	Yes	No
a) "Advertised" as available.	☐	☐
☐ Within Agency ☐ Within NASA		
☐ Within DoD ☐ To GSA		
b) Stored under maintenance.	☐	☐
c) Stored without maintenance.	☐	☐
d) Scrapped.	☐	☐
e) ______________________	☐	☐

5.10 Was a requirement that GSE be designed for common usage at both factory and launch base:

	Yes	No
a) considered?	☐	☐
b) traded off for cost-effectiveness?	☐	☐
c) actually implemented (for some items)?	☐	☐

5.11 How long (average) is GSE held by program before:

a) advertising availability to other programs? ☐ Months

b) salvaging or scrapping of equipment? ☐ Months

c) delivery to other user or agency? ☐ Months

d) ______________________________ ☐ Months

5.12 Is there any policy or procedure for interchange of GSE items between:

	Yes	No
a) NASA Centers?	☐	☐
b) NASA and AF?	☐	☐
c) Not known.	☐	☐

5.13 Does lack of common "definitions" for GSE items cause a problem in identifying multiple usage or commonality considerations?

☐ Yes ☐ No

5.14 Do you believe that a GSE catalog should be established (catalog is a collection of one-sheet specifications with standard format and GSE nomenclature)?

☐ Yes ☐ No

6. DEFINITIONS AND COSTS OF GSE ELEMENTS

6.1 What categories or groupings of GSE or AGE (titles) were employed to describe the elements of GSE hardware in this program (See Appendix B for definitions), and what was the percentage of contractor-supplied GSE total cost for each?

	Category Used	% of GSE Cost
a) Ground Handling Equipment	☐	☐ %
b) Transportation Support Equipment	☐	☐
c) Ground Servicing Equipment	☐	☐
d) Mechanical Support Equipment	☐	☐
- ☐ MSE - ☐ MAGE		
e) Electrical Support Equipment	☐	☐
☐ ESE ☐ EAGE		
f) Test and Support Equipment	☐	☐
g) Checkout Equipment	☐	☐
h) Test Equipment	☐	☐
i) System Test Equipment	☐	☐
j) Special Test Equipment	☐	☐
k) Test Aids and Auxiliary Test Equipment	☐	☐
l) Bench Test Equipment	☐	☐

6.1 (Continued)

	Category Used	% of GSE Cost
m) Subsystem/Component Test Equipment	☐	☐ %
n) Manufacturing Support Equipment	☐	☐
o) Factory Test Equipment	☐	☐
p) Launch Complex Equipment	☐	☐
q) ______________________	☐	☐
r) ______________________	☐	☐
s) ______________________	☐	☐

6.2 In terms of functional application of contractor-supplied GSE, indicate approximate cost (percentage of 100% cost) of GSE to each of the following categories.

a) Handling and Transport	☐ %
b) Servicing	☐
c) Test and Checkout (including launch control equipment)	☐
d) ______________________	☐
Total	100 %

6.3 What was relative usage of contractor-furnished GSE (as portions of percentages used in 6.2)?

	Contractor Factory Only	Launch Base Only	Both Factory & L.B.
a) Handling and Transport	☐ %	☐ %	☐ %
b) Servicing	☐	☐	☐
c) Test and Checkout (including launch control equipment)	☐	☐	☐
d) ______________	☐	☐	☐

$\underbrace{\hspace{6cm}}_{100\%}$

6.4 In terms of functional application of government-furnished GSE, indicate approximate cost (percentage of 100% cost) of GSE to each of the following categories.

a) Handling and Transport	☐ %
b) Servicing	☐
c) Test and Checkout	☐
d) ______________	☐
	100 %

6.5 What was relative usage of government-furnished GSE (as portions of percentages used in 6.4)?

	Contractor Factory Only	Launch Base Only	Both Factory & L.B.
a) Handling and Transport	☐ %	☐ %	☐ %
b) Servicing	☐	☐	☐
c) Test and Checkout	☐	☐	☐
d) ____________	☐	☐	☐

$\underbrace{\hspace{6em}}_{100\%}$

6.6 What percentage of total GSE cost was related to work on new equipment or modification of existing equipment?

		Contractor Equipment	GFE
a) Handling and Transport	New -	☐ %	☐ %
	Mod -	☐ %	☐ %
b) Servicing	New -	☐	☐
	Mod -	☐	☐
c) Test and Checkout	New -	☐	☐
	Mod -	☐	☐
d) ____________	New -	☐	☐
	Mod -	☐	☐

$\underbrace{\hspace{6em}}_{100\%}$

6.7 What was the approximate cost breakdown (%) of the contractor-supplied equipment (including both development and hardware costs)?

a) Deliverable Contractor GSE ☐ %

b) Non-Deliverable Contractor GSE ☐ %

Total Contractor GSE 100 %

6.8 What was the relative value of additional government-furnished GSE?

a) Contractor-supplied ☐ %

b) GFE ☐ %

Total GSE 100 %

6.9 Was minimum GSE cost identified as a program objective in the RFP?

☐ Yes ☐ No

6.10 Was an actual low-cost for GSE (relative to total program cost) achieved for the program?

	Yes	No
a) Contractor-supplied GSE	☐	☐
b) Government-supplied GSE	☐	☐

What is estimated percentage of GSE? (relative to total program cost) ☐ %

6.11 What were the approximate program costs (excluding post-launch operations cost) vs GSE costs)?

a) $ ☐ Total Integrated Spacecraft Program

b) $ ☐ Total Spacecraft Contractor Program

c) $ ☐ Total Contractor-supplied GSE

d) $ ☐ Total Government-supplied GSE

6.12 Of the total value (100%) of GSE at contractor plant after contract completion, what % was:

	Contractor-Supplied	GFE
a) retained at contractor plant for use on follow-on contract? ______	☐ %	☐ %
b) stored at contractor plant; no identified further usage? ______	☐	☐
c) shipped to government facility? ______	☐	☐
d) ______	☐	☐
	100%	

6.13 What percentage of contractor-supplied GSE was provided to support new facilities for this program?

(Provide in terms of portion of 100% given in 6.2) ______ ☐ %

6.14 What was approximate allocation of 100% contractor GSE costs to the following:

a)	Planning and requirements	☐ %
b)	Design Engineering and Development	☐
c)	Sustaining Engineering	☐
d)	Procurement/Purchase/Lease	☐
e)	Manufacture of new GSE	☐
f)	Modification of existing GSE	☐
g)	Qualification Testing	☐
h)	Acceptance Testing	☐
i)	Installation & Checkout (of GSE)	☐
j)	Maintenance of GSE	☐
k)	Documentation (Drawings, Specs, Oper. Instruct., etc.)	☐
l)		☐
m)		☐
	Total	100%

6.15 Did your answers to previous cost questions include any costs for contractor activities after launch?

	Yes	No
a) Sustaining GSE engineering?	☐	☐
b) Maintenance of GSE?	☐	☐
c)	☐	☐

6.16 Is there a separate cost value recorded for each item of GSE on the total GSE list for:

	Yes	No
a) Contractor-supplied GSE	☐	☐
b) Government-furnished GSE	☐	☐

GSE QUESTIONNAIRE

SPECIAL NOTES AND INSTRUCTIONS

(1) Purpose of Questionnaire

Answers to this questionnaire are being acquired, assembled, and analyzed for the NASA/HQ, Low Cost Systems Office, by Lockheed Missiles and Space Company (LMSC) as part of a current study contract on Low Cost Program Practices.

It is hoped that the answers to this GSE questionnaire and analysis of the summarized results will provide NASA/HQ with sufficient base for altering to lower cost versions some of existing NASA general practices affecting procurement of, design performance requirements for, and general usage of GSE.

(2) Completeness/Correctness of Answers

It is desired that answers be as correct and meaningful as possible without going into minute detail. If actual data are not available, estimate judgment answers are preferred to "no answer".

(3) Request for Supplemental Data

Supplemental data pertinent to elaboration of some of your answers are desirable and can be attached to the completed questionnaire. Data particularly helpful would include copies of (a) GSE Plan, (b) a listing of GSE used on the project (identifying existing, modified or new designs and equipment), and possibly (c) some cost breakouts of GSE dollars on major GSE items.

(4) Limitation on Scope

For the purposes of this questionnaire, only GSE required for use through launch operations is to be included. Those equipment such as tracking, data acquisition centers, and operational control centers are beyond the present scope of this survey and analysis.

(5) Use of Separate Questionnaire for Each Program

It is preferred that a separate questionnaire be used for each space program. If general answers covering a series of programs is the only response that can be provided, please list all programs used as a reference for your answers.

(6) Handling of Contacts and Questionnaires

Contact has been made with your Agency or Company separately on another of the study tasks relative to a general PER survey (Program Effects Relationships) Questionnaire (covered by document LMSC-D387544) involving personal interviews. It is hoped that your receipt and response to this GSE Questionnaire will be possible in time for the PER survey staff from LMSC to pick up the filled-in GSE Questionnaire and, perhaps, discuss it with your GSE specialist(s).

If personal contact is not possible, it is requested that your filled-in questionnaire be mailed to the address shown under "LMSC Contacts".

Telecon contacts with LMSC personnel listed to clarify or refine questions or answers are strongly solicited so that minimum turn-around time for completed questionnaire return can be obtained.

LMSC Contacts:

a) Please direct all inquiries or special information by telephone to LMSC:

Dale Hannaford	Orgn. 61-50	(408) 742-8207
Ken Urbach		(408) 742-5036
Wayne Miller		(408) 743-1845

b) For information that must be mailed, please address to:

Wayne Miller, Advanced Payload Systems
Lockheed Missiles & Space Company, Inc.
Space Systems Division
Orgn. 61-50, Bldg. 104
P. O. Box 504
Sunnyvale, California 94088

DEFINITION OF TERMS RELATING TO GROUND SUPPORT EQUIPMENT

1. GSE TERMINOLOGY

Many terms are used throughout Government and Industry to describe Ground Support Equipment, elements thereof, and closely-related equipment. The following definitions are offered to aid in the understanding of and in responding to the Questionnaire.

1.1 Ground Support Equipment (GSE) is a generic term for all support equipment required to handle, transport, test, checkout, service, maintain, or otherwise support a spacecraft. Sometimes the scope of GSE is limited to apply only to equipment used at a launch base; it is also sometimes extended to cover control centers and tracking/data acquisition equipment for flight operations on some programs.

In the Low-Cost Program Practices Study "GSE" has been used to describe equipment used in the factory that supports the same types of functional activities that may be required at the launch base or for transport to the launch base. Post-launch support equipment is specifically excluded from the GSE Analysis study task because of scope limitations.

1.2 Aerospace Ground Equipment (AGE) is a generic term used primarily by the Air Force, but also used on some NASA programs as the equivalent of GSE. It is normally, but not always, deliverable on an Air Force contract, by the DD-250 process, and is required in order to support a spacecraft during acceptance testing, transport, and launch base activities thru lift-off.

1.3 Support Equipment (SE) is also a generic term that must be defined for a specific program. (For example, on the Shuttle program tooling was lumped with SE for the DDT&E phase and defined as that equipment and tooling required to manufacture, refurbish, test, transport, handle, assemble, checkout, service and disassemble the solid rocket motors and component parts thereof, including Factory Support Equipment, Transportation Support Equipment, Special Test Equipment, and Tooling. Launch Base GSE was specifically excluded.

1.4 Mechanical Support Equipment (MSE) is that support equipment (GSE, SE, or AGE) which is primarily mechanical in nature or function. Typical examples include Lift Slings, Spreader Bars, Dollies and Transporters, Shipping Containers, Air Conditioners, Optical Alignment Equipment, Pneumatic and Hydraulic Servicing Carts, Mass Properties Determination Equipment, Solar Panel Deployment Mechanism Test Equipment, Spacecraft Access Stands/Ladders and Leak Test Equipment.

1.5 Ground Handling and Transport Equipment (GSHE) is that class of GSE or Mechanical Support Equipment used to lift, position, physically support, move, protect, store, ship or transport a spacecraft or spare major components thereof during final assembly, test, storage, shipment, and at the launch base for unloading, inspection, test, and mating with the launch vehicle. Typical items of GSHE are Slings, Handling Rings, Spreader Bars, Dollies, Transporters, Shipping Containers, Impact Recorders and Temperature/Humidity Indicators.

1.6 Ground Servicing Equipment is that class of GSE or Mechanical Support Equipment used to provide hydraulic, pneumatic, propellant and gas services and environmental conditioning to a spacecraft during system testing or at the launch base. Typical items include "Brako" carts, Nitrogen Pressurant Carts, Propellant Transfer Units, Air Conditioning Units, and Helium Service Carts.

1.7 Transportation Support Equipment (TSE) is usually considered as part of the Ground Handling Equipment (GSHE) or Ground Handling and Transport Equipment sub-catagories of GSE. However, in the shuttle solid rocket motor procurement it was a part of SE, with equivalent GSE for launch base functions to be determined.

1.8 Mechanical AGE (MAGE) is essentially equivalent to Mechanical Support Equipment.

1.9 Electrical Support Equipment (ESE) is that support equipment (GSE, SE, or AGE) which is primarily electrical or electronic in nature. Typical examples include RF Test Console, Pyrotechnic Test Cable, Battery Charger, IR Simulator, Spacecraft Test (breakout or junction) Boxes, Blockhouse Console, and Dummy Loads.

1.10 Electrical AGE (EAGE) is essentially equivalent to ESE.

1.11 System Test Equipment (STE) is that test equipment used to perform acceptance tests on the total spacecraft system before delivery and/or shipment to the launch base. Depending upon where integration of the mission equipment/payload with the spacecraft takes place, the system test equipment at the factory or assembly plant may or may not include elements to test the mission equipment. System Test Equipment may be GSE or may be designated as FTE or Special Test Equipment, (also abbreviated STE); another common acronym is Vehicle Test Equipment (VTE).

1.12 Special Test Equipment (STE) is equipment and associated software that is of a special nature and required for conducting a specific test. The term is so broad that it must be defined for each program. It may or may not be equivalent to System Test Equipment, also abbreviated STE.

1.13 Spacecraft Test Equipment is a general term which includes all test equipment used to test the Spacecraft, Experiments, Integrated Spacecraft or portions thereof.

1.14 Test and Checkout Equipment is that portion of GSE, both electrical and mechanical, which is primarily required to support systems level tests at the spacecraft assembly/test factory and to support checkout, integration with the launch vehicle, combined launch vehicle checkout and countdown at the launch base. It is synonomous with Test and Support Equipment.

1.15 <u>Test and Support Equipment (T&SE)</u> is GSE that may be required for assembly and test of a spacecraft and/or for servicing and checkout at the launch base.

1.16 <u>System Test Complex (STC)</u> is a facility equipped to perform comprehensive system testing at the spacecraft level. It contains selected portions of the subsystem GSE or SE which are incorporated into the System Test Equipment.

1.17 <u>Launch Complex Equipment (LCE)</u> is composed of selected portions or duplicates of STE/STC and additional equipment as may be necessary to operate a spacecraft, verify its flight readiness, and condition it for launch. It is usually GSE.

1.18 <u>Bench Test Equipment (BTE)</u> is equipment used for acceptance testing of government-furnished equipment (GFE) as well as contractor procured equipment. It normally applies to the component or black box level items of spacecraft and mission equipment. It may also be used for "Bench Integration Test" when required.

1.19 <u>Test Aids and Auxiliary Test Equipment (TA & ATE)</u> are those special items and test devices required to check out and troubleshoot a spacecraft during final assembly and system test. Typical items are breakout boxes, jumpers, cable assembles, dummy squibs (squib simulators), multimeters, oscilloscopes, antenna hats, optical targets, and dummy loads. Usually these items are not deliverable, but there are exceptions, particularly when they are used at the launch base. There is some overlap in defintion with ESE for some items.

1.20 <u>Chamber Equipment</u> is a subset of System or Special Test Equipment. It covers items required to support spacecraft tests in environmental chambers, and is not a term having widespread usage.

1.21 Factory Test Equipment (FTE) is usually that equipment needed to verify the success of fabrication, assembly, or process at the piece part or component level. It is generally common equipment, not unique to the needs of a single spacecraft program, and usually not considered as GSE. (See STE)

1.22 Factory Support Equipment (FSE) is a sub-category under Support Equipment, as used on the Shuttle solid rocket program, and is not part of GSE. It is primarily electrical, mechanical and other support equipment dedicated to the manufacturing process.

1.23 Manufacturing Support Equipment (MSE) may include some MAGE and EAGE to support spacecraft assembly and test functions. Usually does not include jigs, fixtures, tooling/machine tools, dies, etc., but may include special alignment equipment. Since the abbreviation "MSE" is also used for Mechanical Support Equipment care must be exercised to relate the usage to that defined for a specific program.

1.24 Maintenance Ground Equipment (MGE) is a functional subdivision of AGE, as used by the USAF, and is that AGE used to support a spacecraft until launch. It includes the equipment required to handle, transport, service, checkout, maintain and safe the spacecraft and is, therefore, equivalent to that portion of GSE that is covered within the scope of the Low-Cost Program Practices Study.

1.25 Operating Ground Equipment (OGE) is the other functional division of AGE (See MGE above) and is that AGE which is a functional part of a program or system and which operates with the spacecraft as an essential operational element. Ground control center equipment and tracking stations are OGE. Therefore, OGE is not within the scope of the Low-Cost Program Practices Study.

1.26 GSE Plan is a document that identifies the support requirements of a spacecraft program and the ground support equipment that will be utilized to satisfy the functional requirements. GSE lists are a basic part of the plan, and identify both design and hardware status as well as quantity. A separate list is usually provided for government-furnished equipment (GFE). Common status categories are "existing", "modify", and "new". In their simplest form the GSE Plan may consist only of GSE lists, while the more elaborate plans will include descriptions of each item of GSE, its usage, source, software requirements, interfaces, and also related equipment such as STE, FTE, FSE, LCE, STC, et., as well as schedules and procedures for installation and checkout of specific items of GSE used with environmental test chambers, system test complexes and launch base servicing and control facilities. The GSE plan sometimes does not exist as a separate document, and on some programs it may be called an "AGE Plan" or "Support Plan".

1.27 GSE Cost is the total dollar amount on the acquisition contract for GSE. This includes costs for design, modification, manufacture or procurement, acceptance test of government-furnished GSE, maintenance, calibration, installation, documentation, storage, and disposition at contract completion. Note that the cost or value of government-furnished or contractor-owned GSE that may be utilized on the acquisition contract is not included, and is often not known.

2. GENERAL TERMS (NON-GSE) USED IN LCPP STUDY

Many terms used in the aerospace community do not have consistent and commonly accepted definitions. This results in communications difficulties and confusion when comparing data from different programs, different government agencies, and various aerospace companies and divisions of these companies. The following definitions are used in the Low-Cost Program Practices Study that LMSC is performing for the Low-Cost Systems Office of NASA Headquarters.

2.1 Agency refers to the actual organization having project responsibility, management, and procurement authority. Within the NASA it is the NASA Centers and the JPL; for Air Force it may be SAMSO, AFCRL, ARPA, etc.

2.2 Customer refers to the Agency buying or issuing the contracts for a system, and their technical advisors/SETD consultants if applicable.

2.3 Contractor refers to the prime contractor for a spacecraft or space-frame.

2.4 Associate Contractor refers to other procurements on a specific project that are sources of GFE to the spacecraft or integrating contractor and/or which involve interfaces or interface coordination. For example, Experiments are often procured by an Agency from an Associate Contractor by separate contract, and are then delivered to the Integration Facility as GFE.

2.5 Integrated Spacecraft and Costs denotes the combination of a basic spacecraft (sometimes referred to by some projects as a "bus") with the experiments or mission equipment. An integrated spacecraft program cost includes all contractor efforts as well as government support costs charged to the program. It excludes post-launch operations for purposes of this Questionnaire.

2.6 Spacecraft is the basic spaceframe plus the subsystems required for orbital flight and basic support for payloads. Typical subsystems provide communications, data storage, telemetry, commands, timing, electrical power, thermal control, attitude control and station keeping, orbit adjust and sometimes fine pointing.

2.7 Spaceframe is the basic structure of a spacecraft, and includes the main interconnecting cable harness and the interface with the booster.

2.8 Experiments refer to the scientific instruments (sensors, controllers, special on-board data systems, cryostats, etc.) that the spacecraft carrier and are the reason or purpose of a particular mission or space program.

2.9 Mission Equipment is used synonymously with "experiments" to denote the flight hardware or "spacecraft payload" for a particular mission.

2.10 Acquisition Phase or Production Phase refers to the hardware procurement activity on a space program. Usually the acquisition phase contract has been preceded by development activity or definition studies that have involved technical and cost trade studies that result in the establishment of preliminary designs, program plans and schedules, and operational requirements. The amount of design, qualification testing, test articles and other development-type activities that are included in the acquisition phase contract varies widely with the government agencies and the nature and maturity of the technology and specific program/project.

2.11 Integration Facility is the location at which the physical elements are combined to make up the next higher level system element. Usually, in this study, it refers to the location at which the Experiments are combined with the Spacecraft to make up the Integrated Spacecraft. It may be the spaceframe or spacecraft contractor factory, a separate contractor or government agency facility, or at the launch base.

2.12 Integration is the activity of combining basic elements or components into a higher level functioning system. Thus, the spacecraft results from the integration of a spaceframe with the subsystems; it, in turn, is integrated with the experiments or mission equipment to provide the complete or integrated spacecraft, which--in turn--is integrated with the booster to make up the launch vehicle.

Lockheed Missiles & Space Company

LCPP-10

ENGINEERING MEMORANDUM

TITLE:	EM NO: LCPP-10
SPACE EXPERIMENT SUPPORT PROGRAM 71-2 COST ANALYSIS	REF:
	DATE: 15 May 1975
AUTHORS:	APPROVAL:
Jolanta B. Forsyth	ENGINEERING SYSTEM ENGRG D L Hannaford

INTRODUCTION

Under contract (NAS W-2752) to NASA Headquarters Low Cost Systems Office LMSC is performing the Low-Cost Program Practices study, to identify NASA practices that contribute to the high cost of space programs. One task is the collection and analysis of pertinent space program history and cost data for a data bank to support the LCPP study and similar studies. This engineering memo presents cost data for the Air Force Space Experiments Support Program 71-2, a low-cost program for which LMSC was integrating contractor and provided the spacecraft.

SESP 71-2 COST ANALYSIS

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EM No. LCPP-10
Date: 15 May 1975

SPACE EXPERIMENTS SUPPORT PROGRAM 71-2

(SESP 71-2) COST ANALYSIS

.1 OBJECTIVE

In order to provide NASA LCSO with historical cost data and insight into low cost practices the Space Experiment Support Program 71-2 (SESP 71-2), which was reported as a low-cost project by Astronautics and Aeronautics in its June 1974 issue, was cost analyzed. The resulting costs were categorized by subsystem and major system level support categories, and a split was made separating the one time non-recurring development costs from the recurring unit and operating costs.

Within the subsystem costs, the costs were further segregated down to the black box or major assembly level to provide as much functional detail as possible within each black box.

In all cost allocations the basic accounting categories of direct labor, overhead, material, and other costs were kept intact and direct labor manhours provided. These data represent actuals in real year dollars as incurred by the SESP 71-2 program.

.2 SESP 71-2 PROGRAM OVERVIEW

.2.1 SESP 71-2 Mission

The Lockheed Missiles and Space Company (LMSC) was awarded the SESP 71-2 contract with the go-ahead date of April 1, 1970. The contract called for LMSC to conduct a combined contract definition, acquisition and operational support phase for SESP Flight 71-2. The mission of SESP Flight 71-2 was to place an approved payload into earth orbit in a manner and configuration necessary to the attainment of total payload objectives, and provide operational support for the payload for the mission lifetime of 6 months. The payload consisted of the following four GFE experiments:

(1) Flexible Solar Array (RTD-806): The RTD-806 solar array experiment was a 6 month minimum flight test to demonstrate the solar array's dynamic and mechanical behavior and power producing capability, and to perform specific reference measurements. (Hughes Aircraft Co.).

(2) Celestial Infrared Measurement (SAMSO-002): The purpose of the SAMSO-002 experiment was to map a portion of the celestial sphere for 3 revs and to demonstrate the life capabilities of the sensor cooler system for 5 months minimum. (Hughes Aircraft Co.).

(3) DASA/ONR Input/Output Experiment (ONR-001): The ONR-001 was an experiment for accumulating data on the D, E, and F ionosphere regions, performing radar and VLF propagation studies, and studying the behavior of energetic electrons for 5 months. (LMSC).

(4) Experiment (NSA-101): This experiment was a flight test to demonstrate and observe the capabilities of the NSA-101 Command and Interface System. (TRW Systems, Inc.).

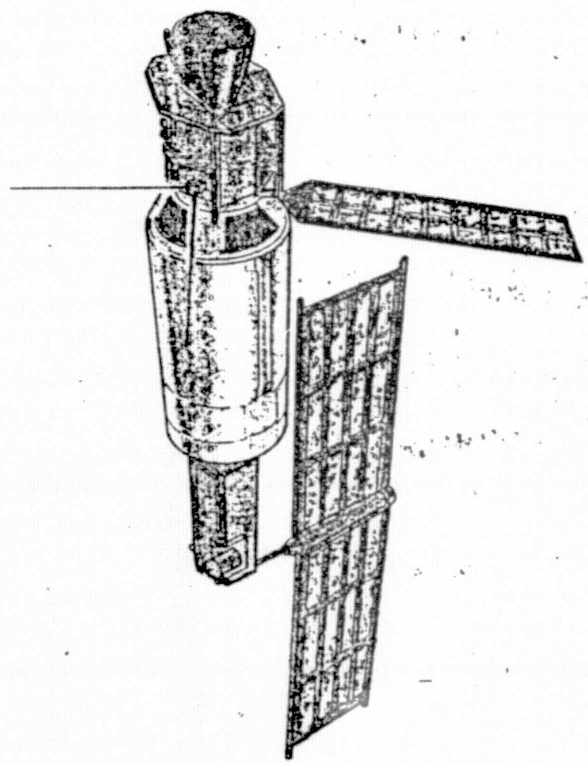
Fig. 2-1 shows an overall view of the SESP 71-2 spacecraft and identifies the major system requirements.

The Space Experiments Support Program (SESP) Office, SMTE, Headquarters Space and Missile Systems Organization (SAMSO), was the overall Air Force Management Agency for this contract. The contract provided for General Systems Engineering/Technical Direction (GSE/TD) to be performed by the Aerospace Corporation under the cognizance of the SESP Office.

.2.2 LMSC Contract Scope

The LMSC contract scope included the following contractor effort:

- o Define a design baseline for government approval for the Spacecraft System,AGE/GHE, interstage adapter, payload fairing, and software. The launch vehicle system/ascent stage/spacecraft concept



MISSION SUPPORT OF

RTD-806	FLEXIBLE SOLAR ARRAY
SAMSO-002	CELESTIAL IR
ONR-001	IONOSPHERIC EFFECTS
NSA-101	BATSON

- ORBIT: 425 ±50 NM
- INCLINATION: 90^0 $(+0,-10^0)$ SUN BETA ANGLE 80-90 DEGREES
- LAUNCH: ~~9-23-71~~ 10-17-71
- SPACECRAFT SUPPORT:
  - POWER
  - TT&C
  - ATTITUDE STABILIZATION
  - THERMAL CONTROL
- LIFE: 6 MONTHS MINIMUM; HIGHLY RELIABLE OPERATION

Fig. 2-1 - SESP 71-2 System Requirements

to be utilized was the Thorad (SLV-2H)/Agena.

- o Plan the detail design, production, test, and support of the Spacecraft System, Spacecraft System AGE/GHE, interstage adapter, payload fairing, and software.
- o Accomplish the detail design, production, experiment integration, test, and support of the Spacecraft System, Spacecraft System AGE/GHE, interstage adapter, payload fairing, and software.
- o Accomplish SESP Flight 71-2 Total Mission System Integration.

The deliverable items were:

- o Spacecraft system
- o Spacecraft system AGE/GHE
- o Interstage adapter
- o Payload fairing
- o Data and reports

.2.3 Program Time Span and Schedule

The initial contract consisted of three phases spanning a total of 24 months with the launch initially scheduled for end of September 1971:

- o Definition Phase - April 1, 1970 through June 1970 (3 months)
- o Acquisition Phase - July 1970 through September 1971 (15 months)
- o Operations Phase - October 1971 through March 1972 (6 months)

The actual launch took place on October 17, 1971, 18.5 months after go-ahead, and the 6 month operations phase was extended twice (6 months each) due to the longevity of the spacecraft. The operational support was terminated in April 1973 resulting in a 36.5 month program span.

Fig. 2-2 shows the major program milestones and activities during the SESP 71-2 definition and acquisition phases. Fig. 2-3 presents the SESP 71-2 integrated mission schedule and Fig. 2-4 details the orbit operations schedule.

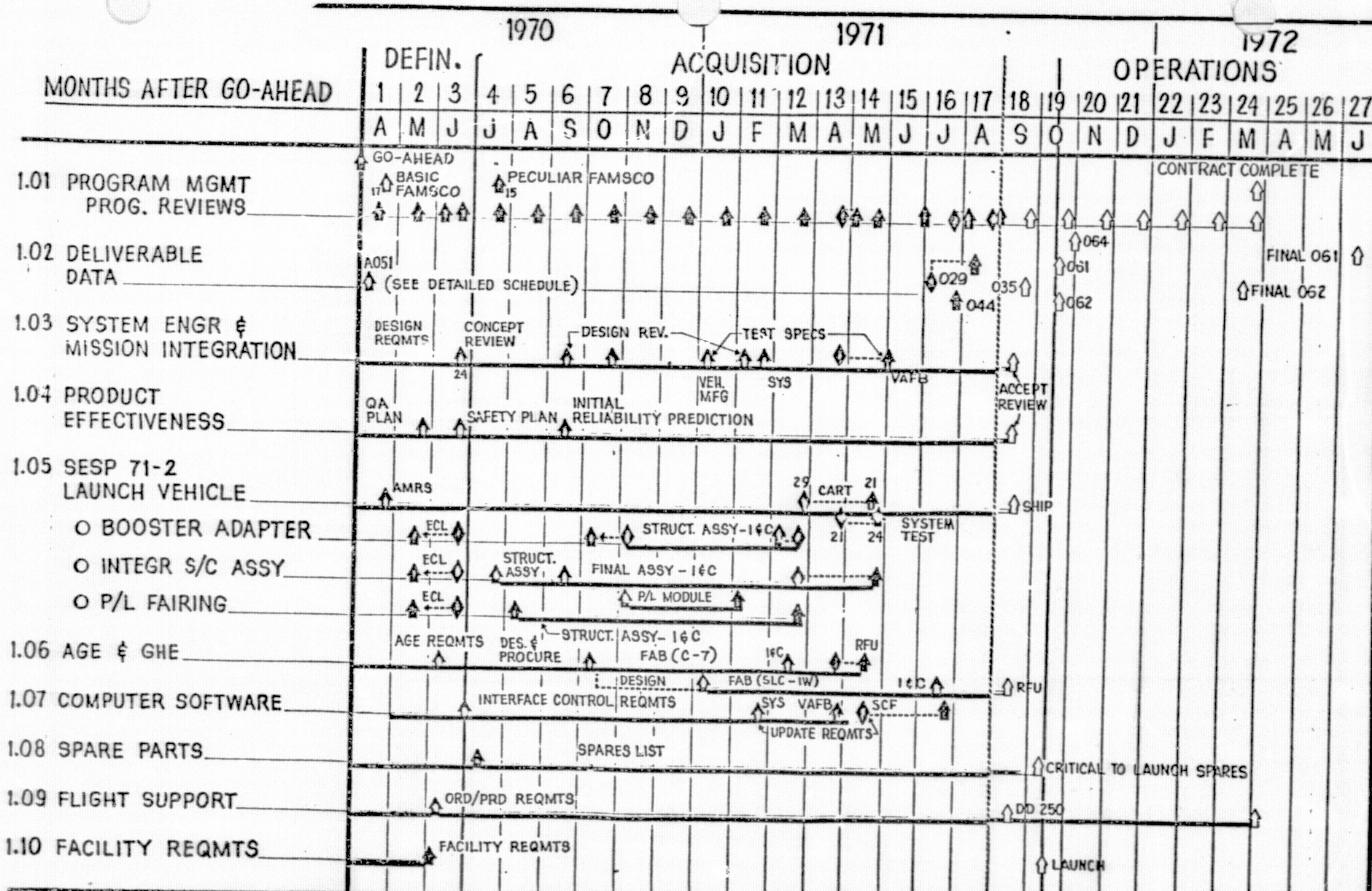


Fig. 2-2 - SESP 71-2 Program Milestones

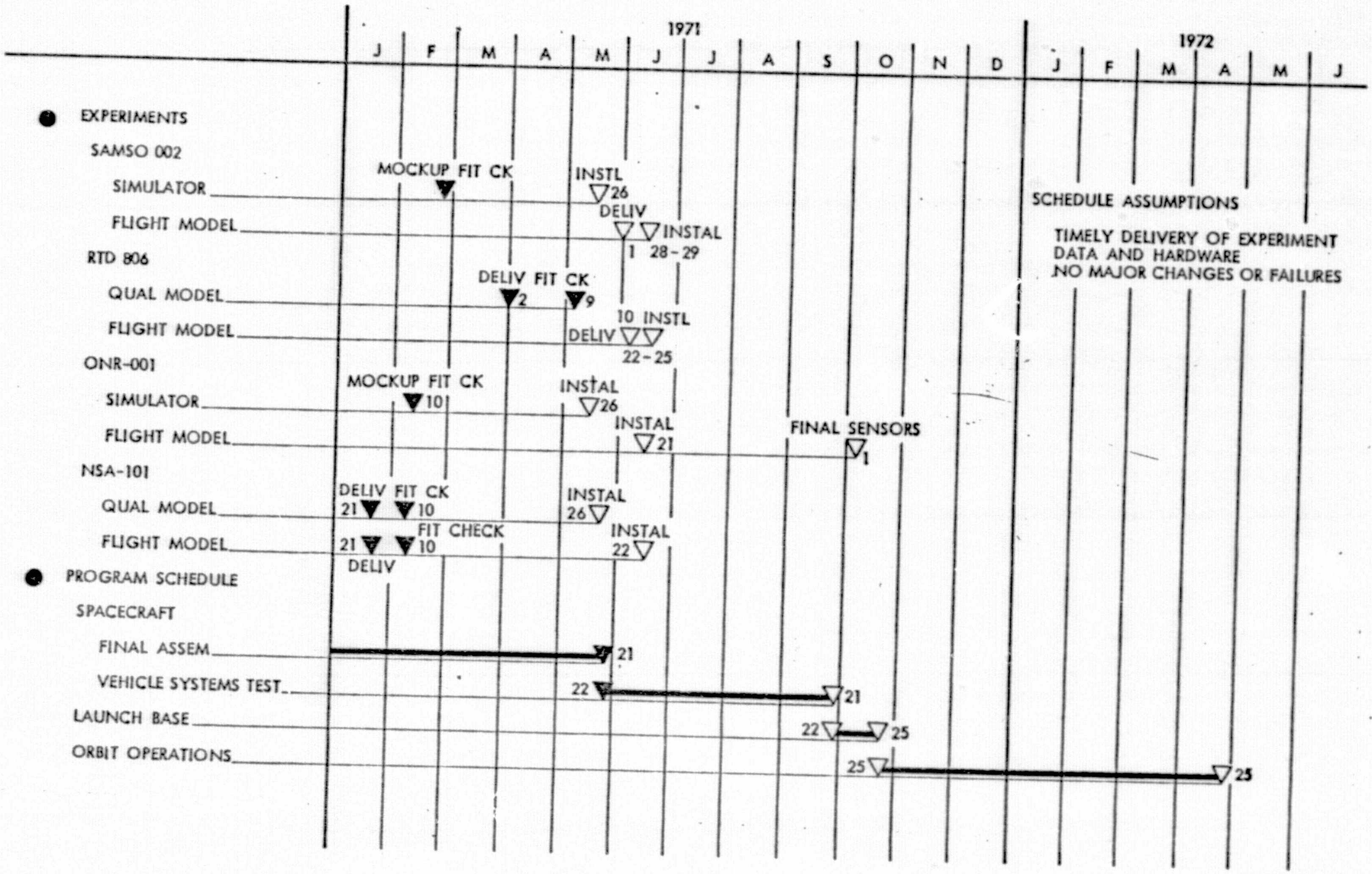


Fig. 2-3 - SESP 71-2 Integrated Mission Schedule

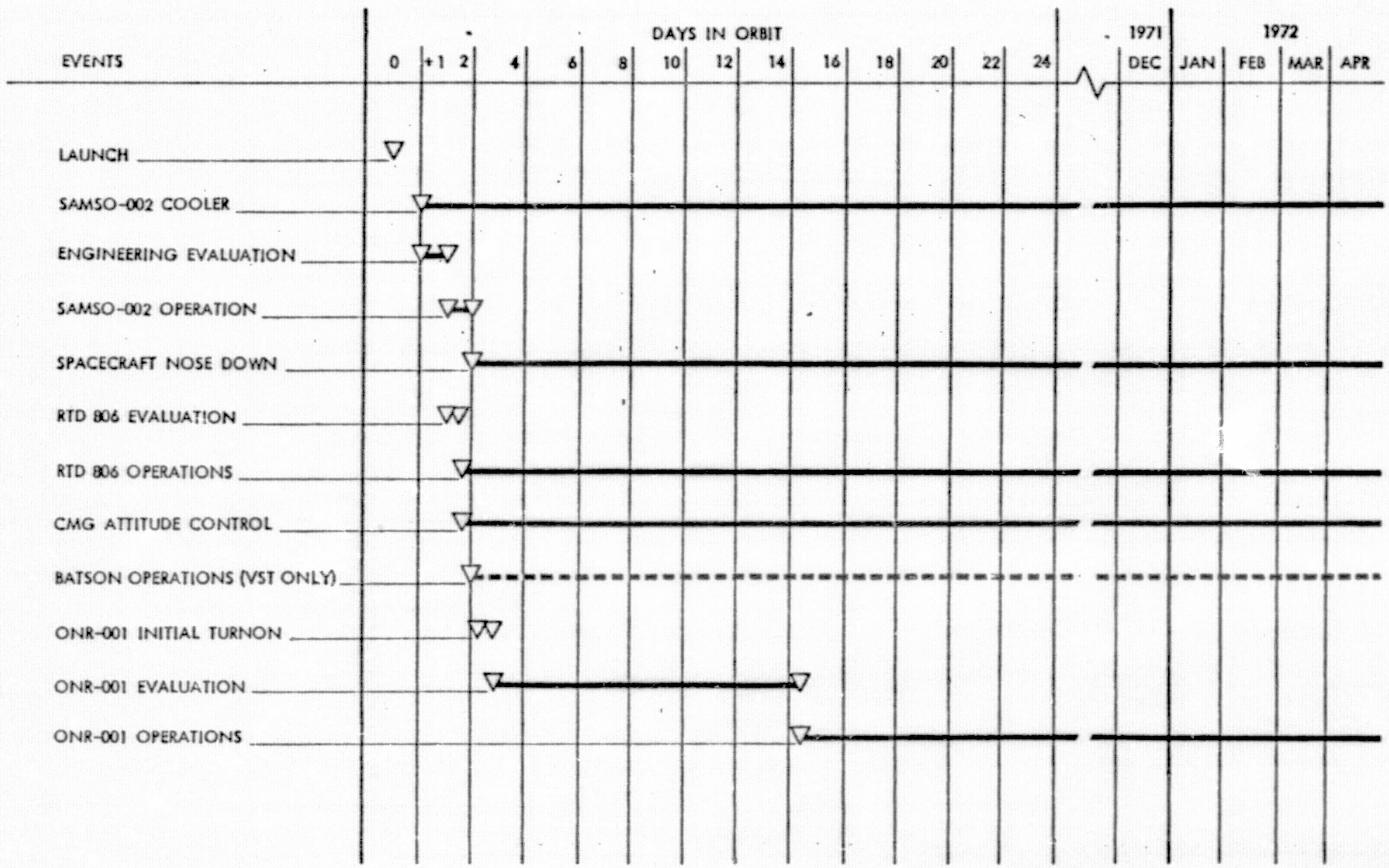


Fig. 2-4 - SESP 71-2 Orbit Operations Schedule

.2.4 General Technical and Other Cost Impacting Data

.2.4.1 Technical

In general SESP 71-2 was a modified Agena upper stage and integrated spacecraft with a dry weight on orbit of 3443 lbs. including 492 lbs. of experiments. It consisted of the following subsystems:

o	Structures	including payload module, forward and aft racks of the Agena, payload fairing, and booster adapter
o	Thermal control	active consisting of the heat exchanger coolant system and passive (blanket and paint)
o	Propulsion	including Agena Bell engine, propellant tank, support structure, plumbing, and pressurization system
o	Electrical	consisting of solar array, batteries and distribution system
o	Stabilization and controls	including inertial reference package (IRP), horizon sensors, CMG's, and N_2 attitude control system
o	TT&C	consisting of PCM telemetry system, two S-band data links, UHF command system, and including two tape recorders and 12 antennas
o	Experiment Support Equipment	including experiment supporting and connecting hardware for the GFE experiments

Detailed description of the technical requirements, performance parameters, and subsystem hardware description is contained in LMSC EM LCPP-7, SESP 71-2 Program History and Spacecraft System Descriptions.

.2.4.2 Inheritance

The SESP 71-2 program had a high degree of inheritance in terms of existing design, off-the-shelf hardware, and support equipment. Approximately 63% of the spacecraft hardware was of existing design, 24% consisted of modified equipment, and 13% represented new equipment. The ground support equipment was about 45% existing, 3% GFE, 29% modified, and 23% new (the latter including a high proportion of ground handling equipment items).

As a result of the high degree of inheritance and confidence placed in mostly flight qualified hardware, the SESP 71-2 program had minimal test hardware (for the new components only) and no complete test vehicles. Fig. 2-5 identifies the components which underwent qualification testing and shows the schedule for such.

For further discussion of inheritance see EM LCPP-11.

.2.4.3 Reliability

The spacecraft reliability requirement was 0.9 for 6 months. In flight the spacecraft far exceeded that, since it operated for more than 18 months.

.2.4.4 Government Furnished Equipment (GFE)

The following major items were furnished as GFE:

- Final Guidance Constants
- Test Complex Items at the Contractor's Facility as Defined in Systems Test Plan
- BTL Guideset Series 600
- BTL Waveguide Converter Kit
- Experiment Test Articles, Simulators and Handling Equipment
  RTD-806
  SAMSO-002 (Flight Article with Sensor Simulator)
  ONR-001 (Flight Article without Sensors)
  NSA-101

C-3

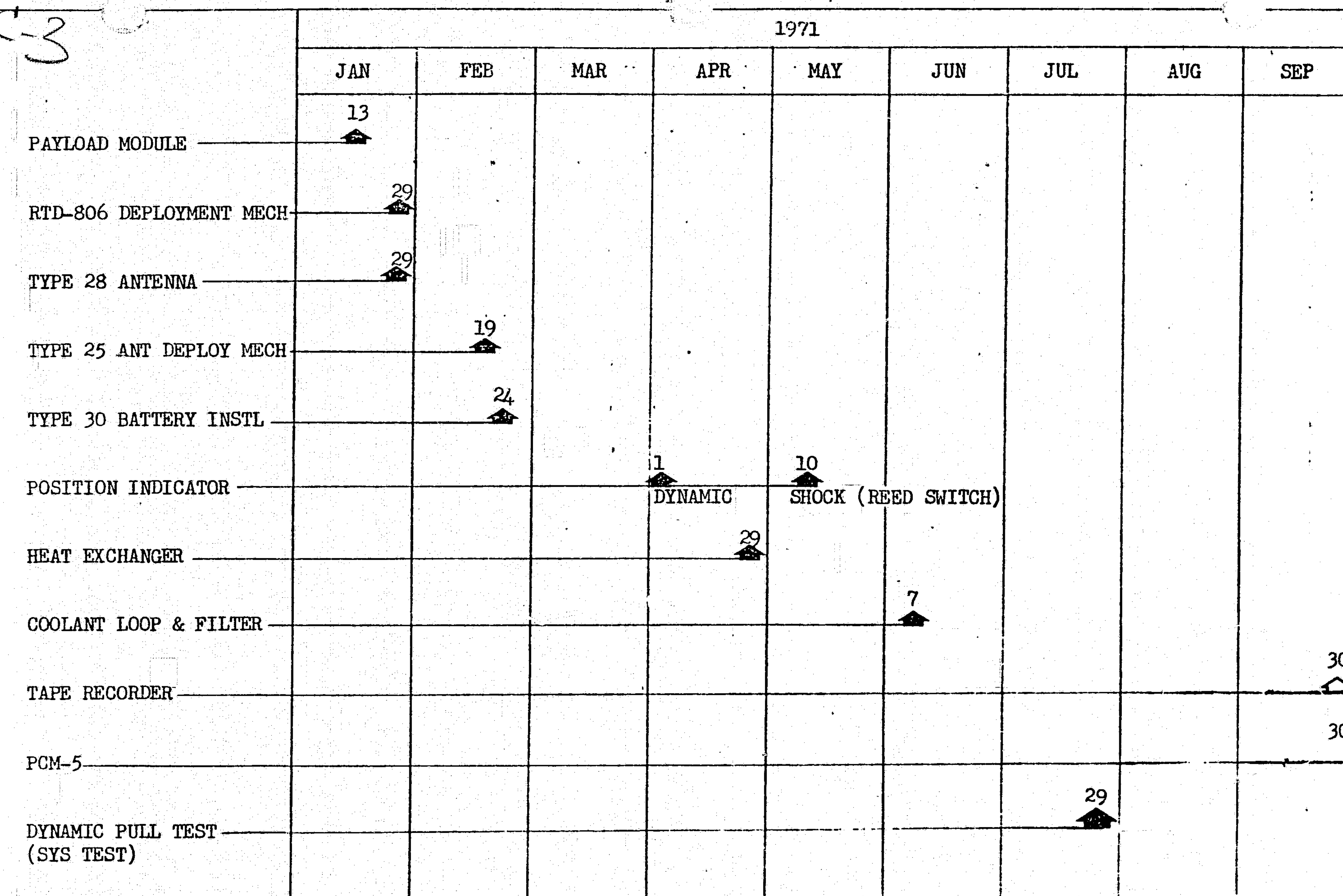


Fig. 2-5 – SESP 71-2 Qualification Test Status

- o Flight Experiments

  RTD-806
  SAMSO-002
  ONR-001
  NSA-101

Also furnished as GFE, or at refurbishment cost to the program, were different black boxes and existing test hardware from other programs. This resulted in $371K cost savings to the program.

.3 HISTORICAL FINANCIAL DATA

.3.1 Contract Data

The SESP 71-2 contract was negotiated at a target cost of $8.525M. It was a CPIF contract with fee range from 0 to 14.5% max. The subcontract portion was estimated at 17.5% and the inplant effort constituted 82.5% of the work.

At the closure of the contract the actual cost was $12.026M with $334K fee (2.8%) representing a price of $12.360M. The actual subcontract portion was 14.5% and 85.5% work was done inplant.

.3.2 Cost Data Records

The financial records used as the source for this cost analysis consisted of labor and material cost accounting tapes, subcontract data, and top level WBS financial reports.

The labor and material costs were charged to over 1500 account numbers, which represented various levels of detail as far as the black box/major assembly level of breakdown and identification was concerned. Therefore not all black box/major assembly costs were retrievable from the historical data. Fig. 3-1 tabulation shows the number of black boxes and major subcontracts identified in SESP cost records.

Subsystem	No. of Isolated Major Assys./Black Boxes	No. of Major Subcontracts*
Structures	4	-
Thermal Control	1	-
Propulsion	3	1
Electrical Power	13	-
Stabilization & Control	8	1
TT&C	14	4
Experiment Support	4	-
Total	47	6

*Major subcontract – over $100K

Fig. 3-1 - SESP 71-2 NR&R Cost Allocation to Black Box Level

The major problem with accounting records of this type is that, with the exception of a few accounts, no provision is made for the non-recurring (NR)/ recurring (R) cost split. In categorizing costs as NR and R requires allocation based on some other guidelines. In this allocation, the SESP schedules such as shown in Fig. 3-2 in conjunction with the opening and closing dates for each account were used as activity time-span guides. Also the nature of the account was categorized as containing NR, R, or both types of cost subject to allocation.

Another problem, apparently inherent in accounting records, has to do with the common charges. These are general accounts for common material, common manufacturing, common quality assurance, etc., and accrue costs in general accounts which have to be then prorated back to the individual direct accounts. Other common accounts were burdens such as material burden, travel, reproduction, and computer charges. All of these required proration back to direct accounts.

.4 SPECIFIC COST ALLOCATIONS AND CHARGES

The following basic cost categories were established for SESP 71-2 actual costs:

o Labor	actual costs and hours as accumulated including overtime (O/T) plus allocated common charges
o Overhead (O/H)	actual costs as accumulated plus allocated common charges
o Material & Parts	actual costs as accumulated plus subcontract dollars (incl. subcontract fee) plus outside production dollars plus allocated minor common material plus allocated procurement burden
o General & Administrative (G&A) and Other Costs	Actual costs as accumulated plus purchased services plus travel plus reproduction plus computer (travel, reproduction, computer: allocations)

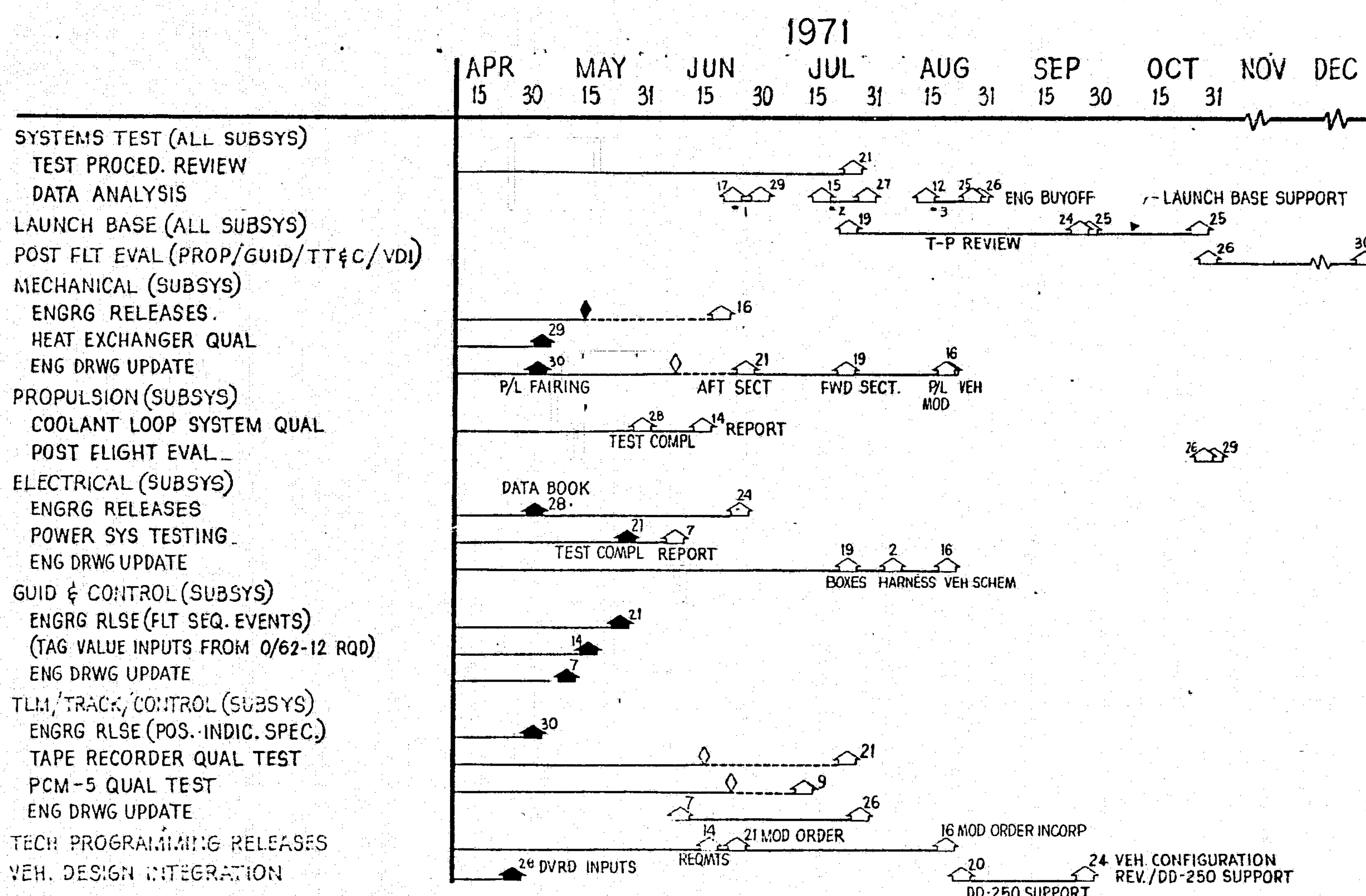


Fig. 3-2 – SESP 71-2 Engineering Schedule

The allocations were made based on these groundrules:

- o Common Changes
  - Common manufacturing prorated to manufacturing
  - Common quality assurance prorated to Q. A.
  - Common technical services prorated to engineering
  - Common repair and maintenance prorated to tooling and test equipment
  - All common prorations based on direct hours
- o Material Burden and Common Minor Material
  - Prorated to material based on direct material dollars
- o Travel
  - 50% allocated to program management
  - 50% allocated to engineering
- o Reproduction
  - 25% allocated to program management
  - 50% allocated to engineering
  - 25% allocated to data
- o Computer
  - 25% allocated to program management
  - 50% allocated to engineering
  - 25% allocated to flight operations

Other functional assumptions:

- o Recurring acceptance test - charged to test
- o In-process inspection - charged to Q. A.
- o In-process factory test - charged to test
- o Manufacturing test equipment - charged to spacecraft test equipment (STE)
- o Final assembly - charged to system integration

.5 SESP 71-2 COSTS

.5.1 Program Cost Summary

The SESP 71-2 non-recurring and recurring costs are summarized in Fig. 5-1. Subsystem costs and hours are followed by the system (program) level functional breakdown and the fee is indicated. All subsystem and system detailed tables show costs only excluding fee. All costs are in real year dollars as incurred by the SESP 71-2 program during 1970/71 time span with some support and operations costs extending into 1972/73.

Fig. 5-2 shows the actual total annual cost spreads as allocated by subsystem and system level cost categories.

The following subsections present the subsystem costs with isolated black box/ major assembly costs identified. The system (program) level cost tables are shown subsequently.

.5.2 Subsystem Costs

The subsystem total costs are broken down by functions at the subsystem level and by functional costs at the black box/major assembly level. For example, the "direction and integration" cost at the black box level contains technical management and integration costs for that box. The given subsystem management and integration is shown separately at the subsystem level. The overall system integration and program management is shown at the system level in a separate tabulation of system level costs.

.5.2.1 Structures

The major structural elements were the spacecraft module, the payload module, the payload fairing, and the booster adapter. The payload module required new design, subsequent redesign due to GFE experiment specification changes, a test article, and static and dynamic testing. The other structural elements were of essentially existing or slightly modified design.

BREAKDOWN	NON-RECURRING DESIGN & DEVEL. COSTS						RECURRING 1st FLIGHT UNIT COSTS						Total $ NR & R
	LABOR			ODC		Total NR $	LABOR			ODC		Total R $	
	Hours	Direct $	O/H $	Pts & Mt'l $	G&A & Other $		Hours	Direct $	O/H $	Pts & Mtl $	G&A & Other $		
SUBSYSTEMS													
STRUCTURES	40957	280.3	301.7	5.1	135.9	723.0	41536	243.5	314.3	170.7	126.2	854.8	1577.8
THERMAL CONTROL	7834	47.7	59.9	14.7	27.4	149.7	407	3.0	3.1	10.7	1.0	17.7	167.3
PROPULSION	1646	11.9	12.2	—	3.8	27.9	4565	24.4	33.9	371.5	15.2	445.0	472.9
ELECTRICAL POWER	36619	240.1	267.7	15.4	137.6	660.8	33568	188.2	257.9	249.9	83.3	779.2	1440.0
STABILIZATION & CONTROL	11384	80.0	81.9	—	34.5	196.4	10214	61.4	76.0	281.0	51.9	470.3	666.7
TELEMETRY TRACK. & COM.	39892	288.3	288.3	188.8	110.7	876.2	26839	180.0	203.7	1124.0	72.3	1579.9	2456.2
EXPERIMENT SUPPT. EQ.	10679	78.7	76.2	19.2	61.3	235.4	2461	20.6	18.5	—	6.2	45.3	280.7
TOTAL	149011	1027.1	1088.0	243.2	511.1	2869.4	119590	721.1	907.4	2207.7	356.0	4192.2	7061.6
SYSTEMS LEVEL													
PROGRAM MGM'T & DATA	15576	121.9	114.8	0.2	105.0	341.9	10788	87.6	81.2	0.1	73.3	242.1	584.0
SYSTEMS ENGINEERING	53765	418.6	389.2	0.2	142.7	950.6	20417	176.1	156.8	0.1	59.0	392.0	1342.6
SYSTEM TEST	14356	97.0	109.0	—	30.5	236.5	36129	238.7	274.3	1.7	83.0	597.8	834.3
SYSTEM INTEG. & FIN. ASSY.	4928	45.7	35.1	—	12.9	93.8	19580	113.1	152.6	23.4	45.5	334.6	428.4
RELIABILITY	9207	81.3	66.7	—	25.0	173.0	6076	52.0	44.6	—	27.3	123.9	296.9
QUALITY ASSURANCE	6956	54.8	51.5	—	16.7	123.0	11009	79.7	80.3	—	26.5	186.6	309.6
S/C TEST EQUIPMENT	29398	182.0	224.4	28.7	126.4	561.4	1898	13.1	14.5	—	6.1	33.7	595.2
GROUND SUPPORT EQUIPMENT	13431	88.4	102.1	76.1	34.9	301.5	875	6.8	6.6	7.4	3.3	24.1	325.6
SPARES & LOGISTICS	—	—	—	—	—	—	282	1.4	2.2	25.2	1.2	30.0	30.0
LAUNCH OPS. & POST-LAUNCH	416	2.6	3.4	—	0.9	6.9	7291	64.6	58.8	14.7	72.5	210.6	217.5
TOTAL	148,033	1092.2	1096.2	105.2	495.0	2788.6	114,345	833.1	872.0	72.6	397.7	2175.4	4964.0
TOTAL PROGRAM COST	297,044	$2119.3	$2184.2	$348.4	$1006.1	$5658.0	233,935	$1554.2	$1779.4	$2280.	$753.7	$6367.6	$12,025.6
(TOT. HRS. = 530,979)													
FEE													334.5
TOTAL SESP 71-2 PRICE													$12,360.1

Note: $ may not add due to rounding; all $ in thousands of real year dollars.

Fig. 5-1 - SESP 71-2 Program Cost Summary

BREAKDOWN	YEARS 1970	1971	1972	1973	TOTAL
Structures	$ 1026	$ 552			$ 1578
Thermal Control	136	31			167
Propulsion	30	443			473
Electrical Power	869	560	$ 11		1440
Stabilization and Control	323	337	7		667
TT&C	1235	1210	11		2456
Experiment Supt. Equip.	195	78	8		281
Subsystems	$ 3814	$3211	$ 37		$ 7062
Prog. Mgm't and Data	$ 226	$ 309	$ 47	$ 2	$ 584
System Engineering	699	618	26		1343
System Test	157	677			834
Sys. Integration & Final Assy.	135	289	4		428
Reliability	140	156	2		298
Quality Assurance	125	180	5		310
STE	315	280			595
GSE	97	224	4		325
Spares & Logistics		28	2		30
Launch Ops. & Supt.		58	127	32	217
System	$ 1894	$2819	$217	$ 34	$ 4964
Total Cost	$ 5708	$6030	$254	$ 34	$12026
Fee	159	167	7	1	334
Total Program	$ 5867	$6197	$261	$ 35	$12360

Fig. 5-2 - SESP 71-2 Annual Cost Spread
(Real Year $ X1000)

Fig. 5-3 shows the structures subsystem costs and direct labor hours as allocated by NR and R breakdown. The subsystem launch operations support identified by subsystem is also shown at the bottom of Fig. 5-3 and is included in the non-recurring and recurring unit costs.

.5.2.2 Thermal Control

The only costs identified with the SESP 71-2 thermal control subsystem were related to the heat exchanger coolant loop system which was a new development item. Its non-recurring cost included building and testing of a qualification unit which was subsequently refurbished with refurbishment costs charged to the recurring unit costs.

Fig. 5-4 shows the heat exchanger costs. It is suspected that the passive thermal control blankets and paint were charged to structures or final assembly. These costs were minor and could not be identified from the SESP records.

.5.2.3 Propulsion

The propulsion subsystems costs are presented in Fig. 5-5. The propulsion subsystem was an off-the-shelf design utilizing the standard Agena engine and propellant tank. The engine was purchased from Bell under a subcontract as shown at the bottom of Fig. 5-5. The engine subcontract breakdown shows Bell costs and manhours with the total price charged to SESP entered under "engine - parts and material" column.

The minor propulsion subsystem non-recurring costs represent essentially SESP start-up costs.

.5.2.4 Electrical Power

The electrical power subsystem and black box costs are tabulated in Fig. 5-6. This subsystem consists primarily of an existing design with some major modifications of change controller, shunt regulator, and power logic assembly boxes, as well as a few minor new components. The solar array was an existing design, but

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BREAKDOWN	NON-RECURRING DESIGN & DEVEL. COSTS						RECURRING 1st FLIGHT UNIT COSTS						Total $ NR & R
	LABOR			ODC		Total NR $	LABOR			ODC		Total R $	
	Hours	Direct $	O/H $	Pts & Mt'l $	G&A & Other $		Hours	Direct $	O/H $	Pts & Mtl $	G&A & Other $		
SUBSYSTEM													
MANAGEMENT	1747	16.8	12.6	0.1	6.2	35.7	726	7.2	5.3		2.6	15.1	50.8
DESIGN & ANALYSIS	7033	50.2	50.5		22.3	123.0	2556	18.9	18.9		7.6	45.4	168.4
INTEGRATION	1228	11.8	8.9		4.4	25.1	1800	17.8	13.2	0.1	6.4	37.5	62.6
MFG. PLANNING & TOOLING	7141	40.5	55.1		14.2	109.8	2139	17.8	16.9		4.3	39.0	148.8
STRUCTURAL TEST SPEC.	531	2.7	4.1	0.4	1.3	8.5							8.5
SUBTOT.	17680	122.1	131.2	0.5	48.3	302.1	7221	61.7	54.3	0.1	20.9	137.0	439.1
SPACECRAFT MODULE													
DIRECTION & INTEGRATION	136	1.1	1.0		0.5	2.6	141	1.2	1.0		0.5	2.7	5.3
DESIGN & ANALYSIS	3385	22.4	24.0		6.7	53.1	1364	9.4	10.3		2.8	22.5	75.6
TOOLING	227	1.2	1.7	0.1	6.1	9.1							9.1
TEST	2133	15.0	17.3		4.4	36.7							36.7
MFG.	456	2.1	3.6	0.2	1.2	7.1	6119	29.1	46.1	17.2	20.3	112.7	119.8
Q.A.	256	1.4	1.9		0.6	3.9	1802	9.7	12.9		4.2	26.8	30.7
STE	264	1.9	2.2	0.1	0.5	4.7							4.7
SUBTOT.	6857	45.1	51.7	0.4	20.0	117.2	9426	49.3	70.3	17.2	27.8	164.7	281.9
PAYLOAD MODULE													
DIRECTION & INTEGRATION	326	2.7	2.4		1.2	6.3	338	2.8	2.5		1.2	6.5	12.8
DESIGN & ANALYSIS	8372	61.9	59.0	1.3	16.4	138.6	1951	14.8	14.7		4.0	33.5	172.1
TOOLING	862	4.7	6.7	1.5	24.6	37.5							37.5
TEST	4229	27.5	31.4	0.9	10.7	70.5	19	0.1	0.1		0.1	0.3	70.8
MFG.	593	2.9	4.4	0.1	1.5	8.9	9858	48.9	77.3	127.6	40.6	294.4	303.3
Q.A.	206	1.1	1.6		0.5	3.2	1884	10.3	14.2		4.5	29.0	32.2
STE	251	1.6	2.0		3.2	6.8							6.8
SUBTOT.	14839	102.4	107.5	3.8	58.1	271.7	14050	76.9	108.8		50.4	363.7	635.4
PAYLOAD FAIRING/SHROUD													
DIRECTION & INTEGRATION	40	0.3	0.3		0.2	0.8	42	0.3	0.3		0.2	0.8	1.6
DESIGN & ANALYSIS	1131	7.9	8.0		2.6	18.5	515	4.1	3.9		1.0	9.0	27.5
TOOLING	45	0.2	0.4	0.5	1.3	2.4							2.4
TEST	42	0.3	0.3		0.1	0.7							0.7
MFG.							7168	34.8	53.9	15.5	15.5	119.7	119.7
Q.A.	22	0.1	0.1		0.1	0.3	812	4.2	5.7		1.9	11.8	12.1
STE	132	0.8	1.0	0.1	3.0	4.8							4.8
SUBTOT.	1412	9.6	10.1	0.5	7.3	27.5	8337	43.4	63.8		18.6	141.2	168.7

Note: $ may not add due to rounding; all $ in thousands of real year dollars.

Fig. 5-3 (sheet 1 of 2) SESP 71-2 Structures Subsystem Costs

BREAKDOWN	NON-RECURRING DESIGN & DEVEL. COSTS: LABOR			ODC		Total NR $	RECURRING 1st FLIGHT UNIT COSTS: LABOR			ODC		Total R $	Total $ NR & R
	Hours	Direct $	O/H $	Pts & Mt'l $	G&A & Other $		Hours	Direct $	O/H $	Pts & Mtl $	G&A & Other $		
BOOSTER ADAPTER													
DESIGN & ANALYSIS	58	0.4	0.4		0.1	0.9							0.9
TOOLING	73	0.4	0.5		2.1	3.0							3.0
MFG.							1725	8.1	12.9	10.4	7.2	38.6	38.6
Q.A.	4					0.1	302	1.6	2.1		0.7	4.4	4.5
STE	8	0.1	0.1			0.1							0.1
SUBTOT.	143	0.9	1.0	–	2.2	4.1	2027	9.7	15.0	10.4	7.9	43.0	47.1
LAUNCH OPS. SUPPORT													
ENGINEERING – PRE LAUNCH	26	0.2	0.2		0.1	0.5	233	2.0	1.8		0.5	4.3	4.8
" – POST LAUNCH							42	0.4	0.3		0.1	0.8	0.8
SUBTOT.	26	0.2	0.2	–	0.1	0.5	275	2.4	2.1	–	0.6	5.1	5.6
STRUCTURES S/S TOTAL	40957	$ 280.3	$ 301.7	$ 5.1	$ 135.9	$ 723.0	41536	$ 243.5	$ 314.3	$ 170.7	$ 126.2	$ 854.8	$ 1577.8
TOT. HRS. = 82,493													

Note: $ may not add due to rounding; all $ in thousands of real year dollars.

Fig. 5-3 (sheet 2 of 2) SESP 71-2 Structures Subsystem Costs

BREAKDOWN	NON-RECURRING DESIGN & DEVEL. COSTS						RECURRING 1st FLIGHT UNIT COSTS						Total $ NR & R
	LABOR			ODC		Total NR $	LABOR			ODC		Total R $	
	Hours	Direct $	O/H $	Pts & Mt'l $	G&A & Other $		Hours	Direct $	O/H $	Pts & Mt'l $	G&A & Other $		
HEAT EXCHANGER													
DIRECTION & INTEGRATION	248	2.2	1.8		0.6	4.7	186	1.7	1.4		0.5	3.6	8.2
DESIGN & ANALYSIS	1768	13.6	12.6		4.5	30.7	20	0.1	0.1		0.1	0.3	31.1
TEST	1378	8.8	10.5	1.2	3.6	24.1							24.1
MFG. & QUAL. UNIT REFURB.	4295	22.3	33.9	13.4	18.4	88.0	192	1.1	1.5	10.7	0.4	13.7	101.7
Q.A.	145	0.7	1.1		0.3	2.1	9		0.1			0.1	2.3
THERMAL S/S TOTAL	7834	$ 47.7	$ 59.9	$ 14.7	$ 27.4	$ 149.7	407	$ 3.0	$ 3.1	$ 10.7	$ 1.0	$ 17.7	$ 167.3
TOT. HRS. = 8241													

Note: $ may not add due to rounding; all $ in thousands of real year dollars.

Fig. 5-4 - SESP 71-2 Thermal Control Costs

BREAKDOWN	NON-RECURRING DESIGN & DEVEL. COSTS						RECURRING 1st FLIGHT UNIT COSTS						Total $ NR & R
	LABOR			ODC		Total NR $	LABOR			ODC		Total R $	
	Hours	Direct $	O/H $	Pts & Mt'l $	G&A & Other $		Hours	Direct $	O/H $	Pts & Mtl $	G&A & Other $		
SUBSYSTEM													
MANAGEMENT	65	0.6	0.5		0.2	1.2	30	0.3	0.2		0.1	0.6	1.8
DESIGN & ANALYSIS	492	4.1	3.5		1.2	8.8	43	0.3	0.3		0.1	0.7	9.5
INTEGRATION	194	1.8	1.4		0.5	3.7	164	1.5	1.2		0.4	3.1	6.8
MFG. PLANNING & TOOLING	775	4.4	6.0		1.5	11.9	232	1.9	1.8		0.5	4.2	16.2
SUBTOT.	1526	10.8	11.3	—	3.4	25.6	469	4.0	3.6	—	1.1	8.6	34.2
ENGINE													
ENG. LIAISON & INTEGR.	120	1.1	0.9		0.3	2.3	152	1.4	1.1		0.4	2.9	5.2
SUBCONTRACT* & PURCH. SERV.										330.4	3.1	333.5	333.5
MFG.							212	1.0	1.7	5.0	0.5	8.1	8.1
Q.A.							71	0.4	0.5		0.2	1.0	1.0
SUBTOT.	120	1.1	0.9	—	0.3	2.3	435	2.7	3.3	335.4	4.2	345.6	347.9
OXIDIZER SUMP													
MFG.							348	1.7	2.6	1.0	0.7	5.9	5.9
Q.A.							122	0.6	0.9		0.3	1.8	1.8
SUBTOT.	—	—	—	—	—	—	470	2.3	3.5	1.0	0.9	7.7	7.7
MISCELLANEOUS PARTS	—	—	—	—	—	—	—	—	—	27.5	—	27.5	27.5
LAUNCH OPS. SUPPORT													
ENGINEERING - POST LAUNCH	—	—	—	—	—	—	21	0.2	0.2	—	0.1	0.4	0.4
PROPELLANT TANK													
MFG.							2403	11.3	18.0	7.6	7.2	44.1	44.1
Q.A.							767	3.9	5.4		1.8	11.1	11.1
SUBTOT.	—	—	—	—	—	—	3170	15.2	23.3	7.6	9.0	55.2	55.2
PROPULSION S/S TOTAL	1646	$11.9	$12.2	—	$3.8	$27.9	4565	$24.4	$33.9	$371.5	$15.2	$445.0	$472.9
TOT. HRS. = 6,211													
* ENGINE SUBCONTRACT													
ENGINEERING							5276	38.2	53.5		42.8	134.5	134.5
MANUFACTURING							8264	41.6	59.8	27.6	66.9	195.9	195.9
TOTAL	—	—	—	—	—	—	13540	$79.8	$113.3	$27.6	$109.7	$330.4	$330.4

Note: $ may not add due to rounding; all $ in thousands of real year dollars.

Fig. 5-5 - SESP 71-2 Propulsion Subsystem Costs

wire harnesses and total system design integration involved considerable design effort. The reuse of existing hardware as GFE or at cost of refurbishment was estimated to contribute about $55K in savings to the SESP electrical power subsystem unit cost.

The electrical engineering launch operations support for this subsystem is included in Fig. 5-6 costs.

.5.2.5 Stabilization and Control (S&C)

This was an off-the-shelf design subsystem with minor modifications of flight controls and timer black boxes. This subsystem, more than any other, benefitted from the reuse of existing hardware. It is estimated that savings of about $286K were realized in the S&C subsystem unit cost due to black box refurbishment and GFE componentry including most of the attitude control items.

The major S&C subcontract for procurement of four control moment gyros (CMG's) is shown at the bottom of Fig. 5-7; identifying subcontractor manhours and costs. All the S&C subsystem costs incurred on the SESP 71-2 are also presented in Fig. 5-7.

.5.2.6 Telemetry, Tracking and Command (TT&C)

The TT&C subsystem involved several new mission critical black boxes. The Pulse Code Modulation Unit type 5 (PCM-5) and Experiment Interface Unit (EIU) required new development and qualification testing. Antenna Type 28 was a new design item and subject to qualification unit and test costs.

Another major TT&C development was the tape recorder. Initial development of type 31 tape recorded failed and this subcontract was terminated. Subsequently type 32 tape recorder was substituted. Both of these subcontracts are shown detailed at the bottom of Fig. 5-8, p.4.

BREAKDOWN	NON-RECURRING DESIGN & DEVEL. COSTS						RECURRING 1st FLIGHT UNIT COSTS						Total $ NR & R
	LABOR			ODC		Total NR $	LABOR			ODC		Total R $	
	Hours	Direct $	O/H $	Pts & Mt'l $	G&A & Other $		Hours	Direct $	O/H $	Pts & Mtl $	G&A & Other $		
SUBSYSTEM													
MANAGEMENT	1857	15.4	13.6		5.9	34.9	811	6.6	6.0		2.6	15.3	50.2
DESIGN & ANALYSIS	8431	57.3	60.9		25.0	143.3	3814	25.0	28.4		11.5	64.9	208.2
INTEGRATION	747	6.2	5.5		2.4	14.1	1756	14.4	13.0		5.7	33.0	47.1
MFG. PLANNING & TOOLING	4592	25.9	35.2		9.1	70.2	1257	10.0	9.9		2.5	22.4	92.5
SUBTOT.	15627	104.8	115.2	—	42.5	262.4	7638	56.0	57.3	—	22.3	135.6	398.0
POWER CONTROL LOGIC ASSY													
DIRECTION & INTEGRATION	374	2.8	3.0		1.2	7.0	155	1.0	1.1		0.5	2.6	9.6
DESIGN & ANALYSIS	1261	7.6	8.8		2.5	18.8	435	2.9	3.2		0.9	7.0	25.9
TOOLING	11	0.1	0.1		0.9	1.1							1.1
TEST	1101	6.7	8.2		2.2	17.1	1107	6.3	8.4		2.7	17.4	34.6
MFG.							1481	6.8	12.2	10.0	2.9	31.9	31.9
Q.A.	33	0.2	0.2		0.1	0.5	458	2.4	3.5		1.1	7.0	7.5
STE	327	1.7	2.5	1.6	6.7	12.5							12.5
SPARES							241	1.1	1.9	2.7	0.6	6.4	6.4
SUBTOT.	3107	18.9	22.9	1.6	13.6	57.0	3877	20.5	30.4	12.7	8.8	72.3	129.3
FORWARD SAFE ARM BOX													
DESIGN	191	1.1	1.3		0.4	2.8							2.8
MFG.							12	0.1	0.1	0.1		0.3	0.3
Q.A.							18	0.1	0.1		0.1	0.3	0.3
SUBTOT.	191	1.1	1.3	—	0.4	2.8	30	0.2	0.2	0.1	0.1	0.6	3.4
SHUNT REGULATORS													
MFG.							534	2.5	4.3	6.8	1.7	15.2	15.2
TOOLING	6				0.2	0.2							0.2
Q.A.	25	0.1	0.2		0.1	0.4	214	1.0	1.6		0.5	3.2	3.5
TEST	215	1.3	1.6		0.4	3.4	651	3.7	5.0		1.6	10.2	13.6
SUBTOT.	246	1.5	1.8	—	0.7	4.0	1399	7.2	10.8	6.8	3.8	28.6	32.6
CHARGE CONTROLLERS													
DIRECTION & INTEGRATION	1061	7.9	7.7		3.4	19.0	249	1.6	1.8		0.8	4.2	23.2
DESIGN & ANALYSIS	3516	24.6	25.0		6.9	56.6	697	5.3	5.3		1.4	12.1	68.6
TOOLING	12	0.1	0.1		0.3	0.5							0.5
TEST	1639	11.6	12.3	6.3	3.4	33.7	395	2.2	3.0		1.0	6.2	39.9
MFG.							385	1.9	3.0	2.9	1.2	8.9	8.9
Q.A.	60	0.3	0.4		0.1	0.9	103	0.5	0.8		0.2	1.5	2.4
STE	1963	10.8	15.3	6.6	42.9	75.6							75.6
SUBTOT.	8251	55.4	60.7	12.9	57.2	186.2	1829	11.5	13.8	2.9	4.6	32.9	219.1

Note: $ may not add due to rounding; all $ in thousands of real year dollars.

Fig. 5-6 (sheet 1 of 3) SESP 71-2 Electrical Power Subsystem Costs

BREAKDOWN	NON-RECURRING DESIGN & DEVEL. COSTS						RECURRING 1st FLIGHT UNIT COSTS						Total $ NR & R
	LABOR			ODC		Total NR $	LABOR			ODC		Total R $	
	Hours	Direct $	O/H $	Pts & Mt'l $	G&A & Other $		Hours	Direct $	O/H $	Pts & Mtl $	G&A & Other $		
BATTERIES													
DESIGN	147	1.0	1.0		0.3	2.3							2.3
SUBCONTRACT - FLIGHT										56.4		56.4	56.4
" - SPARES										27.9		27.9	27.9
SUBTOT.	147	1.0	1.0	—	0.3	2.3	—	—	—	84.3	—	84.3	86.6
WIRE HARNESSES													
DIRECTION & INTEGRATION	920	6.9	6.6		3.0	16.4	258	1.6	1.9		0.8	4.3	20.8
DESIGN & ANALYSIS	3064	17.5	21.4		6.0	44.9	747	4.5	5.7		1.5	11.7	56.7
MFG.							7983	35.5	65.3	15.4	15.8	131.9	131.9
Q.A.							1189	5.9	8.9		2.9	17.6	17.6
SUBTOT.	3984	24.4	28.0	—	9.0	61.4	10177	47.5	81.8	15.4	21.0	165.7	227.0
FUSE RESISTOR J-BOX													
DESIGN							34	0.2	0.3		0.1	0.5	0.5
MFG.							298	1.3	2.3	0.5	0.6	4.7	4.7
Q.A.							33	0.2	0.2		0.1	0.5	0.5
TEST	98	0.6	0.7		0.2	1.5	157	0.9	1.1		0.4	2.4	3.9
STE	133	0.7	1.0	0.2	2.8	4.7							4.7
SUBTOT.	231	1.3	1.7	0.2	3.0	6.2	522	2.5	3.9	0.5	1.1	8.0	14.2
POWER DISTRIBUTION J-BOX													
MFG.							84	0.4	0.6	2.1	0.2	3.3	3.3
Q.A.							25	0.1	0.2		0.1	0.4	0.4
TEST							113	0.6	0.8		0.3	1.7	1.7
SUBTOT.	—	—	—	—	—	—	222	1.1	1.6	2.1	0.5	5.3	5.3
AC POWER & TLM J-BOX													
MFG.							753	3.3	5.6	3.6	2.9	15.5	15.5
Q.A.							85	0.4	0.6		0.2	1.2	1.2
TEST	8		0.1			0.1	249	1.4	1.7		0.6	3.7	3.8
SUBTOT.	8	—	0.1	—	—	0.1	1087	5.1	7.9	3.6	3.7	20.4	20.5
DC POWER & TLM J-BOX													
MFG.							901	4.0	6.7	5.1	1.9	17.7	17.7
Q.A.							92	0.4	0.6		0.2	1.3	1.3
TEST	8		0.1			0.1	115	0.6	0.8		0.3	1.7	1.8
SUBTOT.	8	—	0.1	—	—	0.1	1108	5.1	8.2	5.1	2.3	20.7	20.8
AFT CONTROL & INSTR. J-BOX													
MFG.							202	0.9	1.5	2.5	0.4	5.3	5.3
Q.A.							57	0.3	0.4		0.1	0.8	0.8
TEST							60	0.3	0.4		0.1	0.9	0.9
SUBTOT.	—	—	—	—	—	—	319	1.5	2.3	2.5	0.7	7.0	7.0

Note: $ may not add due to rounding; all $ in thousands of real year dollars.

Fig. 5-6 (sheet 2 of 3) SESP 71-2 Electrical Power Subsystem Costs

BREAKDOWN	NON-RECURRING DESIGN & DEVEL. COSTS						RECURRING 1st FLIGHT UNIT COSTS						Total $ NR & R
	LABOR			ODC		Total NR $	LABOR			ODC		Total R $	
	Hours	Direct $	O/H $	Pts & Mt'l $	G&A & Other $		Hours	Direct $	O/H $	Pts & Mtl $	G&A & Other $		
DESTRUCT DISCRETE J-BOX													
MFG.							7		0.1		3.5	3.6	3.6
Q.A.							9		0.1			0.1	0.1
TEST							63	0.3	0.4		0.1	0.9	0.9
SUBTOT.	—	—	—	—	—	—	79	0.4	0.6	—	3.7	4.7	4.7
SOLAR ARRAY LEAF													
MFG.							1802	8.0	13.4	98.3	3.5	123.2	123.2
Q.A.	87	0.6	0.6		0.2	1.4	375	1.9	2.6	0.5	0.7	5.7	7.1
TEST	813	5.6	5.7		1.6	12.9	450	2.4	3.1		0.9	6.5	19.4
TOOLING	724	4.4	5.4	0.5	1.4	11.7							11.7
STE	728	4.0	5.3	0.3	1.4	11.0							11.0
SUBTOT.	2352	14.6	17.0	0.8	4.6	37.0	2627	12.3	19.2	98.8	5.1	135.4	172.4
MISCELLANEOUS PARTS	—	—	—	—	—	—	—	—	—	12.5	—	12.5	12.5
ELECTRICAL EXPERIMENT SUPPORT EQUIPMENT													
DIRECTION & INTEGRATION	518	3.9	3.7		1.7	9.2	197	1.3	1.4		0.6	3.3	12.6
DESIGN & ANALYSIS	1673	11.2	12.3		3.4	26.9	563	3.7	4.3		1.2	9.2	36.1
TEST	161	1.2	1.1		0.3	2.6	94	0.5	0.6		0.2	1.4	4.0
MFG.							577	2.6	4.3	2.5	0.9	10.3	10.3
Q.A.							101	0.5	0.7		0.2	1.4	1.4
STE	90	0.5	0.6		0.9	2.1							2.1
SUBTOT.	2442	16.8	17.8	—	6.3	40.9	1532	8.6	11.4	2.5	3.2	25.6	66.5
LAUNCH OPS. SUPPORT													
ENGINEERING – PRE LAUNCH	25	0.2	0.2		0.1	0.4	228	1.6	1.7		0.5	3.8	4.2
" – POST LAUNCH							894	7.1	6.9		1.9	15.9	15.9
SUBTOT.	25	0.2	0.2	—	0.1	0.4	1122	8.7	8.6	—	2.3	19.7	20.1
ELECTRICAL S/S TOTAL	36619	$240.1	$267.7	$15.4	$137.6	$660.8	33568	$188.2	$257.9	$249.9	$83.3	$779.2	$1440.0
TOT. HRS. = 70,187													

Note: $ may not add due to rounding; all $ in thousands of real year dollars.

Fig. 5-6 (sheet 3 of 3) SESP 71-2 Electrical Power Subsystem Costs

BREAKDOWN	NON-RECURRING DESIGN & DEVEL. COSTS						RECURRING 1st FLIGHT UNIT COSTS						
	LABOR			ODC		Total NR $	LABOR			ODC		Total R $	Total $ NR & R
	Hours	Direct $	O/H $	Pts & Mt'l $	G&A & Other $		Hours	Direct $	O/H $	Pts & Mtl $	G&A & Other $		
SUBSYSTEM													
MANAGEMENT	694	5.2	4.9		2.0	12.1	276	2.2	2.0		0.8	5.0	17.1
DESIGN & ANALYSIS	3383	24.8	24.1		9.4	58.3	349	2.4	2.5		0.9	5.8	64.1
INTEGRATION	2547	19.0	18.2		7.4	44.5	1173	9.2	8.7		3.5	21.3	65.8
MFG. PLANNING & TOOLING	1324	7.4	10.1		2.6	20.1	328	2.5	2.6		0.7	5.7	25.8
SUBTOT.	7948	56.3	57.3	—	21.4	135.0	2126	16.2	15.8	—	5.8	37.8	172.8
GUIDANCE J-BOX													
DESIGN	117	0.9	0.8		0.2	1.9							1.9
MFG.							782	3.4	5.8	5.3	2.3	16.8	16.8
Q.A.							124	0.6	0.9		0.3	1.7	1.7
TEST	34	0.2	0.2		0.1	0.5	547	3.0	4.0		1.3	8.4	8.9
SUBTOT.	151	1.1	1.0	—	0.3	2.4	1453	7.0	10.7	5.3	3.9	26.9	29.3
FLIGHT CONTROLS													
DIRECTION & INTEGRATION	170	1.3	1.2		0.5	3.0	153	1.2	1.1		0.4	2.7	5.8
DESIGN & ANALYSIS	374	2.3	2.6		0.7	5.7	168	1.3	1.2		0.3	2.8	8.5
TEST	430	2.5	3.0		0.8	6.4	795	4.6	5.9		1.9	12.4	18.7
MFG.							1029	4.5	7.8	9.1	2.3	23.7	23.7
Q.A.							328	1.6	2.3		0.8	4.7	4.7
STE	102	0.5	0.7		1.9	3.1							3.1
SUBTOT.	1076	6.7	7.6	—	3.9	18.2	2473	13.2	18.3	9.1	5.7	46.4	64.6
STANDARD SEQUENCE TIMER													
DIRECTION & INTEGRATION	170	1.3	1.2		0.5	3.0	153	1.2	1.1		0.4	2.7	5.8
DESIGN & ANALYSIS	361	2.7	2.5		0.7	5.9	141	1.1	1.0		0.3	2.4	8.3
TEST	55	0.3	0.4		0.1	0.8	301	1.7	2.1		0.7	4.5	5.3
MFG.							195	0.9	1.5		17.4	19.8	19.8
Q.A.							28	0.1	0.2		0.1	0.4	0.4
STE	24	0.1	0.2		0.7	0.9							0.9
SUBTOT.	610	4.4	4.3	—	2.0	10.7	818	4.9	6.0	—	18.9	29.8	40.5
AUXILIARY SEQUENCE TIMER													
DIRECTION & INTEGRATION	170	1.3	1.2		0.5	3.0	153	1.2	1.1		0.4	2.7	5.8
DESIGN & ANALYSIS	376	2.7	2.6		0.7	6.1	99	0.7	0.7		0.2	1.6	7.7
TEST	47	0.3	0.3		0.1	0.7	159	0.9	1.2		0.4	2.4	3.1
MFG.							152	0.7	1.1	2.7	7.5	12.1	12.1
Q.A.							10	0.1	0.1			0.2	0.2
STE	10	0.1	0.1		0.3	0.4							0.4
SUBTOT.	603	4.4	4.2	—	1.6	10.2	573	3.5	4.2	2.7	8.6	19.0	29.2
MISCELLANEOUS PARTS	—	—	—	—	—	—	—	—	—	13.7	—	13.7	13.7

Note: $ may not add due to rounding; all $ in thousands of real year dollars.

Fig. 5-7 (sheet 1 of 2) Stabilization and Control Subsystem Costs

BREAKDOWN	NON-RECURRING DESIGN & DEVEL. COSTS						RECURRING 1st FLIGHT UNIT COSTS						Total $ NR & R
	LABOR			ODC		Total NR $	LABOR			ODC		Total R $	
	Hours	Direct $	O/H $	Pts & Mtl $	G&A & Other $		Hours	Direct $	O/H $	Pts & Mtl $	G&A & Other $		
TEMPERATURE SENSORS & SIGNAL CONDITIONER													
MFG.							148	0.6	1.1	1.0	0.7	3.4	3.4
Q.A.							41	0.2	0.3		0.1	0.6	0.6
TEST	8		0.1			0.1	85	0.5	0.6		0.2	1.3	1.4
SUBTOT.	8	—	0.1	—	—	0.1	274	1.3	2.0	1.0	1.0	5.3	5.4
CONTROL MOMENT GYROS													
DESIGN & ANALYSIS	100	0.7	0.7		0.2	1.6							1.6
SUBCONTRACT *										150.0		150.0	150.0
SUBTOT.	100	0.7	0.7	—	0.2	1.6	—	—	—	150.0	—	150.0	151.6
GUIDANCE MODULE ASSY.													
MFG.							844	4.1	6.5	15.0	4.1	29.7	29.7
Q.A.							213	1.0	1.6		0.5	3.1	3.1
TEST	46	0.3	0.3		0.1	0.7	364	2.1	2.8		0.9	5.7	6.4
REPLACEMENT IRP GYRO										6.4		6.4	6.4
HORIZON SENSORS										77.7		77.7	77.7
ACCELEROMETER VENDOR ENG					3.0	3.0							3.0
SUBTOT.	46	0.3	0.3	—	3.1	3.7	1421	7.2	10.8	99.1	5.5	122.6	126.3
3TL GUIDANCE SET (GFE) SUPPT.													
Q.A.							54	0.3	0.4		0.1	0.8	0.8
TEST							10	0.1	0.1			0.2	0.2
SUBTOT.	—	—	—	—	—	—	64	0.3	0.5	—	0.1	0.9	0.9
S&C EXPER. SUPPT. EQUIP.													
DIRECTION & INTEGRATION	264	2.0	1.9		0.8	4.7	237	1.8	1.7		0.7	4.2	8.9
DESIGN & ANALYSIS	561	4.0	4.3		1.2	9.4	8	0.1	0.1			0.2	9.6
SUBTOT.	825	6.0	6.2	—	1.9	14.1	245	1.9	1.8	—	0.7	4.4	18.5
LAUNCH OPS. SUPPT.													
ENG. — PRE LAUNCH	17	0.1	0.1		0.1	0.3	150	1.2	1.1		0.3	2.6	2.9
ENG. — POST LAUNCH							617	4.8	4.8		1.3	10.9	10.9
SUBTOT.	17	0.1	0.1	—	0.1	0.3	767	6.0	5.9	—	1.6	13.5	13.8
S&C SUBSYSTEM TOTAL	11384	$80.0	$81.9	—	$34.5	$196.4	10214	$61.4	$76.0	$281.0	$51.9	$470.3	$666.7
TOT. HRS. = 21,598													
* CMG SUBCONTRACT MANUFACTURING	—	—	—	—	—	—	7578	$37.1	$47.8	$26.1	$39.0	$150.0	$150.0

Note: $ may not add due to rounding; all $ in thousands of real year dollars.

Fig 5-7 (sheet 2 of 2) Stabilization and Control Subsystem Costs

BREAKDOWN	NON-RECURRING DESIGN & DEVEL. COSTS						RECURRING 1st FLIGHT UNIT COSTS						Total $ NR & R
	LABOR			ODC		Total NR $	LABOR			ODC		Total R $	
	Hours	Direct $	O/H $	Pts & Mt'l $	G&A & Other $		Hours	Direct $	O/H $	Pts & Mtl $	G&A & Other $		
SUBSYSTEM													
MANAGEMENT	1636	14.8	11.9		5.6	32.3	691	6.2	5.1		2.4	13.7	46.0
DESIGN & ANALYSIS	5472	40.9	39.1		16.1	96.0	2143	16.0	16.0	0.7	6.6	39.4	135.4
INTEGRATION	1871	17.0	13.7		6.4	37.1	2670	23.9	19.7		9.1	52.7	89.8
MFG. PLANNING & TOOLING	1542	8.6	11.7		3.1	23.4	382	2.9	3.0		0.8	6.6	30.0
SUBTOT.	10521	81.4	76.4	—	31.0	188.8	5886	49.0	43.8	0.7	18.9	112.4	301.2
PULSE CODE MODULATION UNIT-TY.													
DIRECTION & INTEGRATION	719	5.7	5.2		2.1	13.0	371	2.9	2.7		1.2	6.9	19.9
DESIGN & ANALYSIS	5230	35.5	37.1		14.1	86.8	86	0.6	0.7		0.3	1.6	88.4
TEST	1676	10.2	12.7		5.7	28.6	941	5.7	7.1		1.9	14.7	43.4
MFG.	208	0.9	1.5	6.5	0.4	9.3	2699	13.6	21.6	42.9	7.5	85.6	94.9
Q.A.	1443	9.0	10.9		5.0	24.8	1549	10.2	11.7		4.9	26.8	51.6
RELIABILITY ENG.	1172	7.5	8.3		3.9	19.8							19.8
STE	176	0.9	1.3	0.8	0.4	3.3							3.3
SUBTOT.	10624	69.8	77.1	7.3	31.6	185.7	5646	33.0	43.8	42.9	15.9	135.6	321.3
EXPERIMENT INTERFACE UNIT													
DIRECTION & INTEGRATION	487	4.0	3.5		1.4	8.9	229	1.8	1.7		0.8	4.3	13.1
DESIGN & ANALYSIS	3013	20.4	21.3		7.6	49.3							49.3
TEST	33	0.2	0.2		0.1	0.6	531	3.0	4.0		1.1	8.1	8.7
MFG.	9		0.1			0.1	787	3.7	6.2	18.9	1.6	30.4	30.6
Q.A.	197	1.3	1.5		0.4	3.2	756	4.8	5.7		2.5	13.0	16.2
STE	526	2.6	3.7	1.9	1.2	9.3							9.3
SUBTOT.	4265	28.5	30.3	1.9	10.7	71.4	2303	13.3	17.6	18.9	5.9	55.8	127.2
DECODER-TYPE 23													
DESIGN & ANALYSIS	133	1.1	0.9		0.3	2.3							2.3
TEST				3.6	3.0	6.6	491	2.8	3.7		1.0	7.5	14.1
MFG.							1178	5.3	8.9	27.1	4.0	45.3	45.3
Q.A.							560	3.3	4.1		2.1	9.5	9.5
RELIABILITY ENG.	593	3.3	4.4		2.0	9.7							9.7
SUBTOT.	726	4.4	5.3	3.6	5.3	18.6	2229	11.4	16.7	27.1	7.1	62.2	80.8
RECEIVER DEMODULATOR-TY. 2													
DESIGN & ANALYSIS	138	1.3	1.0		0.3	2.5							2.5
PURCHASED PARTS										37.5		37.5	37.5
SUBTOT.	138	1.3	1.0	—	0.3	2.5	—	—	—	37.5	—	37.5	40.0
PULSE CODE MODULATION UNIT-TY. 3													
DESIGN & ANALYSIS	128	0.9	0.9		0.3	2.1							2.1
MFG. / PURCH. PARTS	112	0.6	0.9		0.3	1.8				23.4		23.4	25.2
TEST	89	0.6	0.7	0.1	0.2	1.6							1.6
SUBTOT.	329	2.1	2.5	0.1	0.8	5.5	—	—	—	23.4	—	23.4	28.9

Note: $ may not add due to rounding; all $ in thousands of real year dollars.

Fig 5-8 (sheet 1 of 4) SESP 71-2 Telemetry, Tracking and Command Subsystem Costs

BREAKDOWN	NON-RECURRING DESIGN & DEVEL. COSTS — LABOR Hours	LABOR Direct $	LABOR O/H $	ODC Pts & Mt'l $	ODC G&A & Other $	Total NR $	RECURRING 1st FLIGHT UNIT COSTS — LABOR Hours	LABOR Direct $	LABOR O/H $	ODC Pts & Mtl $	ODC G&A & Other $	Total R $	Total $ NR & R
TRANSMITTER – TYPE 20													
DIRECTION & INTEGRATION	40	0.3	0.3		0.1	0.7	38	0.3	0.3		0.1	0.7	1.4
DESIGN & ANALYSIS	418	3.8	3.0		0.8	7.6							7.6
SUBCONTRACT (1)										168.6		168.6	168.6
Q.A.							248	1.7	1.8		0.6	4.1	4.1
SUBTOT.	458	4.1	3.3	—	0.9	8.3	286	2.0	2.1	168.6	0.7	173.5	181.8
RECEIVER DEMODULATOR – TY. 4													
DIRECTION & INTEGRATION	40	0.3	0.3		0.1	0.7	38	0.3	0.3		0.1	0.7	1.4
DESIGN & ANALYSIS	445	4.1	3.2		0.9	8.1							8.1
SUBCONTRACT (1)										50.4		50.4	50.4
Q.A.							73	0.5	0.5		0.2	1.2	1.2
SUBTOT.	485	4.4	3.5	—	1.0	8.8	111	0.8	0.8	50.4	0.3	52.3	61.1
BASEBAND ASST. UNIT – TY. 3													
DESIGN & ANALYSIS	257	2.3	1.9		0.5	4.7							4.7
SUBCONTRACT (1)										39.8		39.8	39.8
Q.A.							57	0.4	0.4		0.1	1.0	1.0
SUBTOT.	257	2.3	1.9	—	0.5	4.7	57	0.4	0.4	39.8	0.1	40.8	45.5
TRANSMITTER – TYPE 21													
DESIGN & ANALYSIS	231	2.1	1.7		0.5	4.3							4.3
SUBCONTRACT (1)										110.6		110.6	110.6
Q.A.							160	1.1	1.2		0.4	2.7	2.7
SUBTOT.	231	2.1	1.7	—	0.5	4.3	160	1.1	1.2	110.6	0.4	113.4	117.7
PULSE CODE MODULATION UNIT – TY. 6 & SUBMULTIPLEXER – TY. 3													
DIRECTION & INTEGRATION	50	0.4	0.4		0.2	0.9	47	0.4	0.3		0.2	0.9	1.8
DESIGN & ANALYSIS – PCM 6	515	3.3	3.6		1.0	7.9							7.9
" & " – SUBM. 3	333	2.2	2.4		0.7	5.3							5.3
SUBCONTRACT (2)										217.0		217.0	217.0
Q.A.							478	3.3	3.6		1.2	8.1	8.1
SUBTOT.	898	5.9	6.4	—	1.9	14.1	525	3.7	3.9	217.0	1.3	225.9	240.1
(1) SUBCONTRACT (4 ITEMS) MANUFACTURING	—	—	—	—	—	—	24584	$ 120.5	$ 109.3	$ 58.8	$ 80.9	$ 369.5	$ 369.5
(2) SUBCONTRACT (2 ITEMS) MANUFACTURING	—	—	—	—	—	—	13,028	$ 63.9	$ 62.1	$ 41.6	$ 49.4	$ 217.0	$ 217.0

Note: $ may not add due to rounding; all $ in thousands of real year dollars.

Fig. 5-8 (sheet 2 of 4) SESP 71-2 Telemetry Tracking and Command Subsystem Costs

BREAKDOWN	NON-RECURRING DESIGN & DEVEL. COSTS						RECURRING 1st FLIGHT UNIT COSTS						Total $ NR & R
	LABOR			ODC		Total NR $	LABOR			ODC		Total R $	
	Hours	Direct $	O/H $	Pts & Mt'l $	G&A & Other $		Hours	Direct $	O/H $	Pts & Mt'l $	G&A Other $		
MAGNETIC TAPE RECORDER													
DIRECTION & INTEGRATION	158	1.2	1.2		0.6	2.9	151	1.2	1.1		0.5	2.8	5.7
DESIGN & ANALYSIS	1744	16.3	12.7		4.1	33.1	660	6.2	4.9		1.3	12.5	45.6
TEST	1936	14.2	13.9	1.6	5.4	35.1							35.1
MTR-TY.31 SUBCONTRACT (3)				173.7		173.7							173.7
MTR-TY.32 SUBCONTRACT (4)										368.3		368.3	368.3
Q.A.							1781	11.1	13.6		4.4	29.1	29.1
SPARES (TY.32 SPARE ABOVE)										1.5		1.5	1.5
SUBTOT.	3838	31.8	27.8	175.3	10.0	244.8	2592	18.5	19.6	369.8	6.2	414.1	658.9
MULTICOUPLER - TYPE 14													
PURCHASED PART	—	—	—	—	—	—	—	—	—	3.9	—	3.9	3.9
INSTRUMENT UNIT - TY. 1													
DESIGN	150	0.8	1.0		0.3	2.1							2.1
MFG.							21	0.1	0.2		(0.8)	(0.6)	(0.6)
Q.A.							3					0.1	0.1
SUBTOT.	150	0.8	1.0	—	0.3	2.1	24	0.1	0.2	—	(0.8)	(0.5)	1.6
ANTENNA SYSTEMS													
DIRECTION & INTEGRATION	443	3.8	3.2		1.3	8.3	246	1.9	1.8		0.8	4.5	12.8
DESIGN - TYPE 25	465	3.2	3.2		0.9	7.4	478	4.2	3.5		1.0	8.7	16.1
- TYPE 28	353	2.7	2.5		0.7	5.9	281	2.5	2.1		0.6	5.2	11.1
- SYSTEM	1741	14.3	12.5		3.5	30.3							30.3
TEST - TYPE 25							16	0.1	0.1			0.2	0.2
- TYPE 28	2638	16.3	19.1	0.5	6.7	42.6	31	0.2	0.2		0.1	0.5	43.1
MFG. - TYPE 25							1374	7.1	10.5	0.4	2.8	20.8	20.8
- TYPE 28	183	1.0	1.3	0.2	0.5	3.0	1241	7.3	9.4	11.2	3.5	31.3	34.3
Q.A. - TYPE 25							526	3.0	3.9		1.3	8.1	8.1
- TYPE 28	120	0.6	0.9		0.2	1.8	370	2.2	2.8		0.9	5.8	7.6
SUBTOT.	5943	41.9	42.8	0.7	13.8	99.1	4563	28.4	34.3	11.6	10.9	85.2	184.3
TT&C EXPER. SUPPT. EQUIP.													
DIRECTION & INTEGRATION	89	0.7	0.7		0.3	1.6	85	0.7	0.6		0.3	1.6	3.2
DESIGN & ANALYSIS	898	6.7	6.5		1.8	15.0	98	0.8	0.7	0.5	0.2	2.2	17.2
TEST							264	1.6	2.0		0.6	4.2	4.2
MFG.							704	4.1	5.8	1.2	1.5	12.5	12.5
Q.A.							79	0.4	0.6		0.2	1.2	1.2
SUBTOT.	987	7.4	7.2	—	2.1	16.7	1230	7.5	9.7	1.7	2.7	21.6	38.3
(3) & (4) SEE NEXT PAGE.													

Note: $ may not add due to rounding; all $ in thousands of real year dollars.

Fig. 5-8 (sheet 3 of 4) SESP 71-2 Telemetry Tracking and Command Subsystem Costs

BREAKDOWN	NON-RECURRING DESIGN & DEVEL. COSTS						RECURRING 1st FLIGHT UNIT COSTS						Total $ NR & R
	LABOR			ODC		Total NR $	LABOR			ODC		Total R $	
	Hours	Direct $	O/H $	Pts & Mt'l $	G&A & Other $		Hours	Direct $	O/H $	Pts & Mtl $	G&A & Other $		
LAUNCH OPS. SUPPT.													
ENG. — PRE LAUNCH	42	0.4	0.3		0.1	0.8	375	3.4	2.9		0.8	7.1	7.9
" — POST LAUNCH							852	7.3	6.6		1.8	15.7	15.7
SUBTOT.	42	0.4	0.3		0.1	0.8	1227	10.8	9.5		2.6	22.8	23.6
TT & C SUBSYSTEM TOTAL	39,892	$ 288.3	$ 288.3	$ 188.8	$ 110.7	$ 876.2	26,839	$ 180.0	$ 203.7	$ 1124.0	$ 72.3	$ 1579.9	$ 2456.2
TOT. HRS = 66,731													
(3) SUBCONTRACT - MTR TY. 31													
ENGINEERING	2592	19.4	18.4		19.7	57.5							57.5
MANUFACTURING	408	2.0	2.1	72.3	39.8	116.2							116.2
TOTAL	3000	$ 21.4	$ 20.5	$ 72.3	$ 59.5	$ 173.7	—	—	—	—	—	—	$ 173.7
(4) SUBCONTRACT - MTR TY. 32													
ENGINEERING							9287	69.8	51.7	9.5	53.1	184.1	184.1
MANUFACTURING							4031	20.0	28.0	83.0	53.2	184.2	184.2
TOTAL	—	—	—	—	—	—	13318	$ 89.8	$ 79.7	$ 92.5	$ 106.3	$ 368.3	$ 368.3

Note: $ may not add due to rounding; all $ in thousands of real year dollars.

Fig. 5-8 (sheet 4 of 4) SESP 71-2 Telemetry Tracking and Command Subsystem Costs

TT&C subsystem involved two more major subcontracts for type 20 transmitters, receiver demodulator type 4, and PCM-6 including submultiplexer type 3. These are itemized in Fig. 5-8, p. 2. Fig. 5-8 shows the total SESP TT&C subsystem costs.

.5.2.7 Experiment Support Equipment

Although SESP 71-2 experiments were GFE, the SESP program was responsible for their integration with the spacecraft. This effort included development and installation of supporting and mounting structures, mechanisms, power distribution, and some instrumentation. The specific equipment hardware costs involved were minor and are included in the particular affected subsystem.

The overall development effort and integration analyses constitute the primary NR costs associated with experiment support equipment and integration and are shown in Fig. 5-9. (These costs do not include experiment ground support equipment, which was primarily GFE).

.5.3 System Costs

The system/program level costs were aggregated in the following cost categories.

- Program Management and Data
- System Engineering
- System Test
- System Integration and Final Assembly
- System Reliability
- System Quality Assurance (Q. A.)
- System Spacecraft Test Equipment (STE)
- Ground Support Equipment (GSE)
- Systems Spares
- System Launch Operations and Support

BREAKDOWN	NON-RECURRING DESIGN & DEVEL. COSTS: LABOR Hours	LABOR Direct $	LABOR O/H $	ODC Pts & Mt'l $	ODC G&A & Other $	Total NR $	RECURRING 1st FLIGHT UNIT COSTS: LABOR Hours	LABOR Direct $	LABOR O/H $	ODC Pts & Mtl $	ODC G&A & Other $	Total R $	Total $ NR & R
SUBSYSTEM													
MANAGEMENT	406	3.4	3.0		1.1	7.5	186	1.6	1.4		0.5	3.5	10.9
DESIGN & ANALYSIS	3200	25.3	23.0		8.5	56.9	945	7.5	6.9		2.5	16.9	73.8
INTEGRATION	1718	14.3	12.6		4.7	31.6	496	4.2	3.7		1.4	9.2	40.8
SUBTOT.	5324	43.0	38.6		14.3	95.9	1627	13.3	12.0		4.4	29.6	125.6
NSA-101 EXPERIMENT SUPPT.													
DESIGN & ANALYSIS	15	0.1	0.1		0.1	0.3							0.3
TEST	239	1.4	1.8		0.6	3.8							3.8
MFG.	135	0.7	0.9	0.1	0.3	2.1							2.1
Q.A.	7		0.1			0.1							0.1
STE	100	0.6	0.8		0.9	2.3							2.3
SUBTOT.	496	2.9	3.7	0.1	1.9	8.6	—	—	—	—	—	—	8.6
SAMSO-002 EXPER. SUPPT.													
DESIGN & ANALYSIS	1223	8.3	7.0		7.6	22.9							
TEST	1147	8.8	8.4		3.0	20.2							
MFG.	882	4.5	7.2	10.2	20.0	41.9							
Q.A.	6		0.1			0.1							
SUBTOT.	3258	21.6	22.6	10.2	30.6	85.1	—	—	—	—	—	—	85.1
ONR-001 EXPER. SUPPT.													
DESIGN & ANALYSIS	81	0.6	0.6	—	0.4	1.6	—	—	—	—	—	—	1.6
RTD-806 EXPER. SUPPT.													
DESIGN & ANALYSIS	1095	8.0	7.8	1.4	6.6	23.8							23.8
TEST	256	1.6	1.5	7.4	7.2	17.7							17.7
MFG.	82	0.4	0.6	0.1	0.2	1.3							1.3
Q.A.	61	0.3	0.5		0.1	1.0							1.0
SUBTOT.	1494	10.4	10.4	8.8	14.1	43.7	—	—	—	—	—	—	43.7
LAUNCH OPS. SUPPT.													
ENG. — PRE LAUNCH	26	0.2	0.2		0.1	0.5	229	1.9	1.8		0.5	4.2	4.6
" — POST LAUNCH							605	5.4	4.8		1.3	11.5	11.5
SUBTOT.	26	0.2	0.2	—	0.1	0.5	834	7.4	6.6	—	1.8	15.7	16.1
EXPERIMENT SUPPT. EQUIP. TOTAL	10,679	$78.7	$76.2	$19.2	$61.3	$235.4	2461	$20.6	$18.5	—	$6.2	$45.3	$280.7
TOT. HRS = 13,140													

Note: $ may not add due to rounding; all $ in thousands of real year dollars.

Fig. 5-9 SESP 71-2 Experiment Support Equipment Costs

Most system level cost tables show two totals. One total represents the costs allocated at the system level only. The other larger total represents the sum of the costs at the system level, as well as those which have been previously allocated to the subsystems. This was done to facilitate cost impact analyses at the total functional level, as opposed to having some of these functions buried in the subsystem costs.

.5.3.1 Program Management and Data

The SESP 71-2 system level program management, configuration and data management, and data costs are shown in Fig. 5-10.

The total system level program and configuration management cost of $477K excludes program management costs of $488.4K allocated to subsystems, test, STE, reliability, Q.A., GSE and systems engineering functions. Thus in reality $965.4K of SESP program costs are due to program and configuration management. (Lower total in Fig. 5-10).

The data costs could only be identified at the system level. These costs represent $107K.

.5.3.2 System Engineering

Fig. 5-11 presents the SESP 71-2 system engineering costs. These consist of requirements analyses and system level engineering analyses. No system engineering costs could be identified with specific subsystems, therefore none were allocated to subsystems. However, as shown in Fig. 5-11 there was system engineering effort allocated to GSE.

Since SESP 71-2 was a high inheritance program with little design engineering effort, system engineering appears as a large percentage of the total program cost.

BREAKDOWN	NON-RECURRING DESIGN & DEVEL. COSTS						RECURRING 1st FLIGHT UNIT COSTS						Total $ NR & R
	LABOR			ODC		Total NR $	LABOR			ODC		Total R $	
	Hours	Direct $	O/H $	Pts & Mt'l $	G&A & Other $		Hours	Direct $	O/H $	Pts & Mtl $	G&A & Other $		
PROGRAM MANAGEMENT													
PRELIMINARY PLANNING	1326	11.5	9.2		8.4	29.1							29.1
PROGRAM COORDINATION	2163	17.2	15.8		14.1	47.1	1554	12.4	11.4		10.1	33.8	80.9
PROGRAM REVIEW/MTGS.	311	2.1	2.2		2.0	6.4	130	1.2	1.0		0.9	3.0	9.4
PROGRAM CONTROLS	5317	45.7	40.6		35.7	122.0	5317	45.7	40.6		35.7	122.0	244.0
SUBTOT.	9117	76.5	67.9	—	60.1	204.6	7001	59.3	53.0	—	46.6	158.9	363.4
CONFIGURATION & DATA MANAGEMENT	3023	25.7	22.1	—	19.7	67.5	1981	18.1	14.9	—	13.1	46.0	113.6
DATA													
CDRL ITEMS - DEF. Φ	219	1.3	1.5		1.6	4.3							4.3
" " - POST DEF. Φ	1537	8.7	11.4		11.5	31.6	1537	8.7	11.4		11.5	31.6	63.1
PRESENTATIONS - DEF. Φ	1411	8.1	9.8	0.1	10.2	28.2							28.2
" - POST DEF. Φ	269	1.6	2.0	0.1	2.0	5.7	269	1.6	2.0	0.1	2.0	5.7	11.4
SUBTOT.	3436	19.6	24.7	0.2	25.3	69.8	1806	10.3	13.4	0.1	13.5	37.2	107.0
SYSTEM P.M. & DATA TOTAL* (TOT. HRS. = 26,364)	15576	$121.9	$114.8	$0.2	$105.0	$341.9	10788	$87.6	$81.2	$0.1	$73.3	$242.1	$584.0
* EXCLUDES:													
PROGRAM MGM'T OF S/S	6405	56.2	46.6	0.1	21.0	123.8	2720	24.0	20.1	—	9.0	53.1	176.8
OTHER (TEST, STE, REL. Q.A. GSE & SYST. ENGRG.)	10080	83.5	74.1	—	33.2	190.8	6418	54.3	47.5	—	18.9	120.8	311.6
TOTAL ALLOCATED P.M.	16485	139.6	120.7	0.1	54.2	314.5	9138	78.3	67.6	—	27.9	173.9	488.4
PROG. MGM'T GRD. TOTAL (EXCLUDING DATA)	28625	$241.9	$210.7	$0.1	$133.9	$586.6	18120	$155.6	$135.5	$0.1	$87.6	$378.8	$965.4

Note: $ may not add due to rounding; all $ in thousands of real year dollars.

Fig. 5-10 SESP 71-2 System Program Management and Data Costs

BREAKDOWN	NON-RECURRING DESIGN & DEVEL. COSTS						RECURRING 1st FLIGHT UNIT COSTS						Total $ NR & R
	LABOR			ODC		Total NR $	LABOR			ODC		Total R $	
	Hours	Direct $	O/H $	Pts & Mt'l $	G&A & Other $		Hours	Direct $	O/H $	Pts & Mtl $	G&A & Other $		
MANAGEMENT & CONTROLS	770	6.5	5.5	—	2.0	14.0	258	2.1	1.9	—	0.7	4.7	18.7
REQUIREMENTS													
CONTAMINATION	10766	88.0	76.7		28.2	192.9	5099	42.3	37.0		13.5	92.8	285.7
INTEG. TEST PROGRAM	7185	61.1	53.4	0.1	19.1	133.6	4031	34.2	30.1		10.7	75.0	208.6
LAUNCH OPS. & TEST	673	5.9	5.1		1.8	12.9	362	3.9	3.1		1.1	8.1	21.0
ORBITAL OPS. PLANS	1075	9.2	8.2		2.9	20.3	6341	56.8	52.4		18.2	127.4	147.7
VEHICLE SYSTEM	1208	7.5	9.2		3.3	20.0	279	2.3	2.3		0.8	5.4	25.4
MISSION SYSTEM	1143	6.8	8.1		3.0	17.9	984	6.6	7.2		2.6	16.4	34.3
INTEG. ON-ORBIT OPS.	1440	12.2	10.9	0.1	3.9	27.1	1440	12.2	10.9	0.1	3.9	27.1	54.1
GSE	1959	15.5	14.2		5.9	35.5							35.5
SUBTOT.	25449	206.3	185.8	0.2	68.0	460.2	18556	158.4	142.9	0.1	50.8	352.3	812.5
ANALYSES													
ORBIT THERMODYNAMICS	5979	40.9	42.9		15.3	99.1	198	1.5	1.5		0.5	3.5	102.6
STRUCTURAL	7183	59.6	51.7		18.3	129.7							129.7
AEROMECHANICS	12033	86.3	86.8		30.8	203.8	393	3.1	3.0		1.0	7.1	210.9
MASS PROPERTIES	2875	20.6	20.5		7.2	48.3	54	0.6	0.6		0.2	1.4	49.6
LAUNCH/ENTRY THERMO.	540	4.0	3.8		1.4	9.2	64	0.5	0.5		0.1	1.1	10.3
DIRECTION & CONTROL	895	9.9	6.4		5.6	21.9	894	9.9	6.4		5.6	21.9	43.8
SUBTOT.	29505	221.3	212.1	—	78.6	512.0	1603	15.6	12.0	—	7.5	35.1	547.0
TOTAL SYSTEMS ENGRG.	55724	$ 434.1	$ 403.4	$ 0.2	$ 148.6	$ 986.2	20417	$ 176.1	$ 156.8	$ 0.1	$ 59.0	$ 392.0	$ 1378.2
(TOT. HRS. = 76,141)													
LESS ALLOCATED TO GSE	1959	15.5	14.2	—	5.9	35.5	—	—	—	—	—	—	35.5
SYSTEMS ENGRG.	53765	$ 418.6	$ 389.2	0.2	$ 142.7	$ 950.6	20417	$ 176.1	$ 156.8	$ 0.1	$ 59.0	$ 392.0	$ 1342.6
(TOT. HRS. = 74,182)													

Note: $ may not add due to rounding; all $ in thousands of real year dollars.

Fig 5-11 SESP 71-2 System Engineering Cost

5.3.3 System Test

The system test costs are shown in Fig. 5-12. These costs include the system level test costs only with the black box/major assembly qualification test costs allocated to appropriate subsystems as shown in the previous figures.

These costs represent complete spacecraft functional systems test as well as integrated (spacecraft and experiments) system test including test support and test data. The GFE experiments were fully tested and accepted by the experimenters prior to the integrated system test. However, due to some discrepancies in experiments, the integrated system test was done twice at the Sunnyvale Test complex C-7. Then final systems test was completed at VAFB after vehicle shipment.

SESP 71-2 was not required to have a system level thermal vacuum test. The electromagnetic compatibility testing was performed on new components only. These cost savings offset the repeated system test costs. Fig. 5-13 shows the SESP integrated systems test schedule and primary activities involved.

5.3.4 System Integration and Final Assembly

The system level integration costs, including the SESP 71-2 vehicle final assembly and checkout costs, are shown in Fig. 5-14. Included in the final assembly cost is a cost for disassembly of an existing DTV (Development Test Vehicle) from another A. F. program. Parts and some structural assemblies from this DTV were used on the SESP 71-2 vehicle with the SESP program paying for the disassembly and refurbishment costs if any were required.

Figures 5-15 and 5-16 show the final assembly and equipment installation schedules, respectively. Also identified are the primary tasks associated with physical SESP 71-2 spacecraft system integration.

BREAKDOWN	NON-RECURRING DESIGN & DEVEL. COSTS						RECURRING 1st FLIGHT UNIT COSTS						Total $ NR & R
	LABOR			ODC		Total NR $	LABOR			ODC		Total R $	
	Hours	Direct $	O/H $	Pts & Mt'l $	G&A & Other $		Hours	Direct $	O/H $	Pts & Mtl $	G&A Other $		
MANAGEMENT & CONTROLS	1219	8.4	9.3		2.5	20.2	1879	13.4	14.1		3.8	31.3	51.5
PLANS & PROCEDURES	9001	62.4	68.3		19.1	149.8	2127	15.4	15.9		4.8	36.1	185.9
COMPUTER SOFTWARE	774	4.4	5.7		1.6	11.8							11.8
CONTAMINATION CONTROL							796	4.3	6.1	0.2	1.7	12.3	12.3
TEST INSTRUMENTATION MODS. & SUPPT.	3362	21.8	25.7		7.2	54.7	49	0.3	0.4		0.1	0.8	55.5
VEHICLE TEST							15047	96.7	114.3		33.1	244.2	244.2
TEST DATA ANALYSIS							12191	82.8	92.7	1.5	30.7	207.8	207.8
TEST DATA DOCUMENTATION							4040	25.8	30.8		8.7	65.3	65.3
SYSTEM TEST TOTAL	14356	$97.0	$109.0	—	$30.5	$236.5	36,129	$238.7	$274.3	$1.7	$83.0	$597.8	$834.3
(TOT. HRS = 50,485)													

Note: $ may not add due to rounding; all $ in thousands of real year dollars.

Fig 5-12 - SESP 71-2 System Test Costs

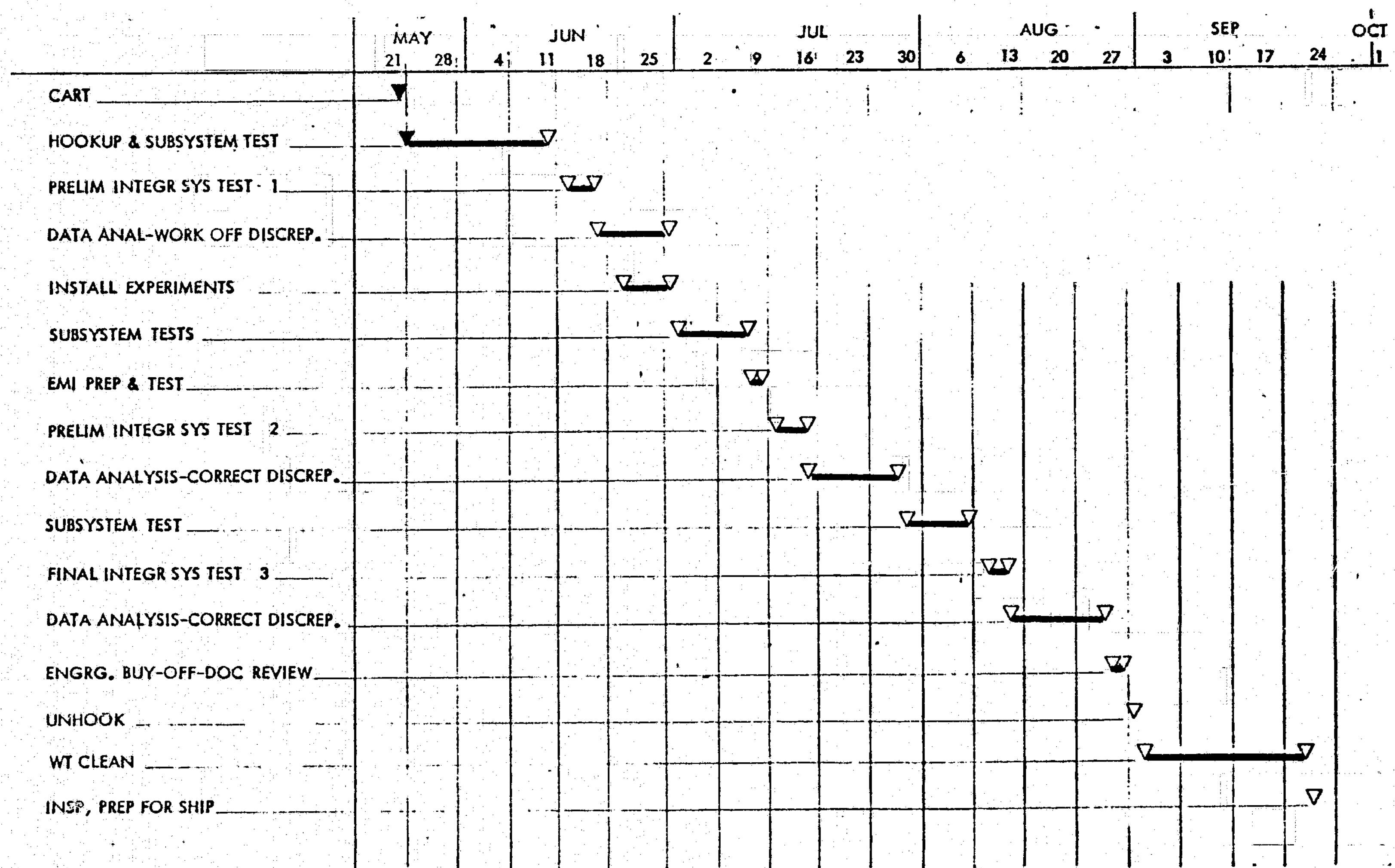

Fig. 5-13 - SESP 71-2 Integrated Systems Test

LOCKHEED MISSILES & SPACE COMPANY, INC.

BREAKDOWN	NON-RECURRING DESIGN & DEVEL. COSTS						RECURRING 1st FLIGHT UNIT COSTS						Total $ NR & R
	LABOR			ODC		Total NR $	LABOR			ODC		Total R $	
	Hours	Direct $	O/H $	Pts & Mt'l $	G&A & Other $		Hours	Direct $	O/H $	Pts & Mtl $	G&A & Other $		
TOTAL MISSION SYSTEMS INTEGRATION	1602	$ 13.6	$ 11.2	—	$ 4.1	$ 28.9	—	—	—	—	—	—	$ 28.9
EXPERIMENT INTERFACE													
LIAISON	3018	29.4	21.8		8.0	59.2	2047	20.1	15.0		5.5	40.7	99.9
CONTAMINATION REQMNTS.	308	2.8	2.1		0.8	5.7							5.7
SUBTOT.	3326	32.2	23.9	—	8.8	64.9	2047	20.1	15.0	—	5.5	40.7	105.6
VEHICLE FINAL ASSY. & C/O													
FINAL ASSY.							6275	31.6	51.2	22.7	13.0	118.5	118.5
INSTALLATION							4642	23.7	35.6		11.9	71.2	71.2
DISASSEMBLE EXIST. DTV							296	1.5	2.2		0.6	4.3	4.3
POST FINAL MODS.& REWK.							2026	13.2	16.5	0.7	4.2	34.5	34.5
IN-PROCESS INSPECTION							4294	23.1	32.1		10.3	65.5	65.5
SUBTOT.	—	—	—	—	—	—	17533	93.0	137.5	23.4	40.0	293.9	293.9
SYSTEM INTEGRATION & FINAL ASSY. TOTAL*	4928	$ 45.7	$ 35.1	—	$ 12.9	$ 93.8	19580	$ 113.1	$ 152.6	$ 23.4	$ 45.5	$ 334.6	$ 428.4
(TOT. HRS. = 24508)													
* EXCLUDES :													
SUBSYSTEM INTEGRATION	14848	121.3	107.8	0.1	45.9	275.1	11678	98.4	86.1	0.1	38.1	222.7	497.8
GSE INTEGRATION	607	4.5	4.5		3.5	12.4	355	2.6	2.6		2.0	7.2	19.7
STE INTEGRATION	1987	13.9	14.8		7.4	36.1	533	3.9	3.9		3.0	10.9	47.0
TOTAL ALLOCATED SYST. INT.	17442	139.8	127.1	0.1	56.7	323.7	12566	105.0	92.6	0.1	43.1	240.8	$ 564.5
SYSTEM INTEGRATION TOTAL (EXCLUDING FINAL ASSY. & C/O)	22370	$ 185.5	$ 162.2	$ 0.1	$ 69.7	$ 417.5	14613	$ 125.1	$ 107.6	$ 0.1	$ 48.6	$ 281.5	$ 699.0

Note: $ may not add due to rounding; all $ in thousands of real year dollars.

Fig 5-14 - SESP 71-2 System Integration and Final Assembly

LCPP-10

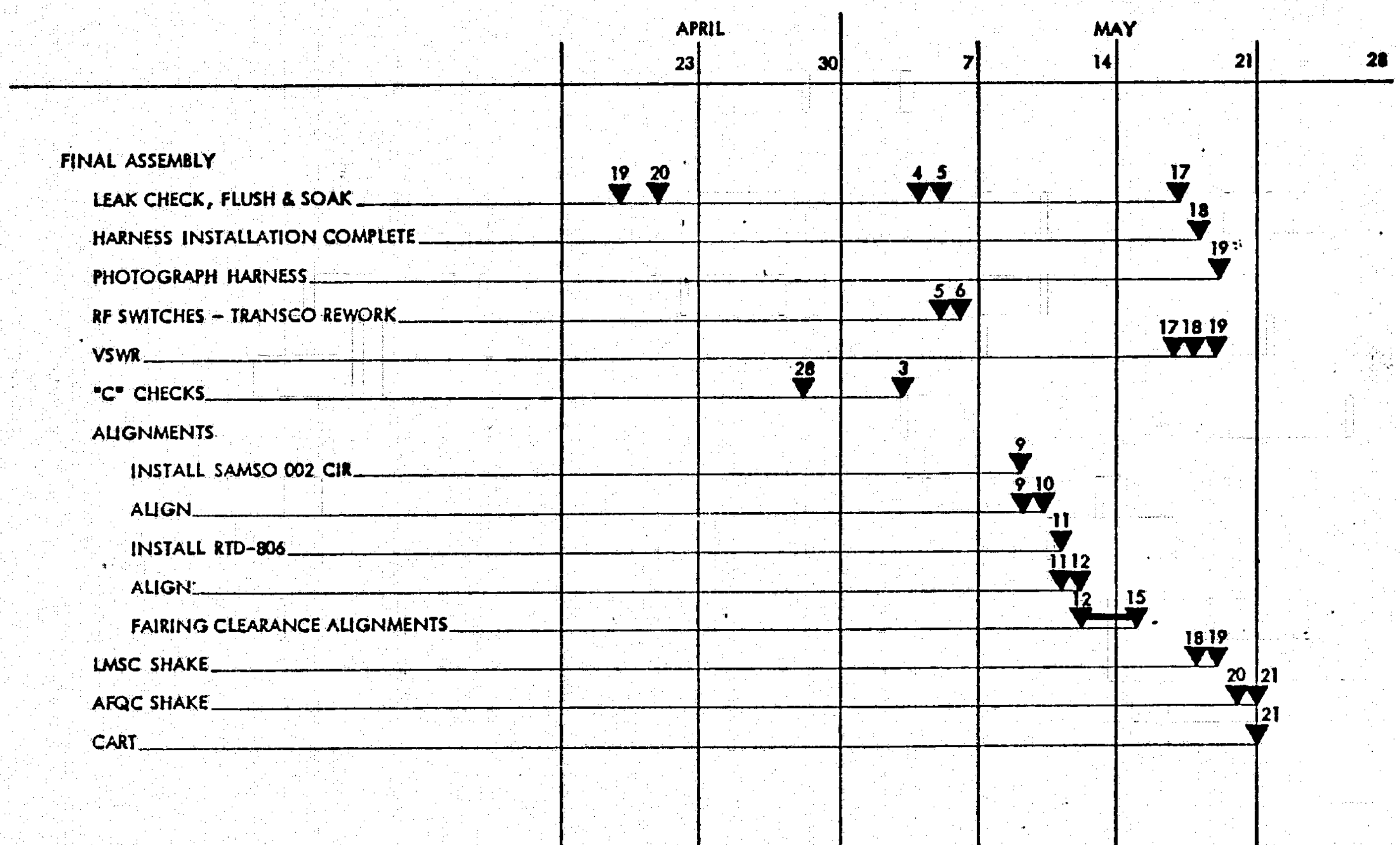

Fig. 5-15 - SESP 71-2 Spacecraft Schedule

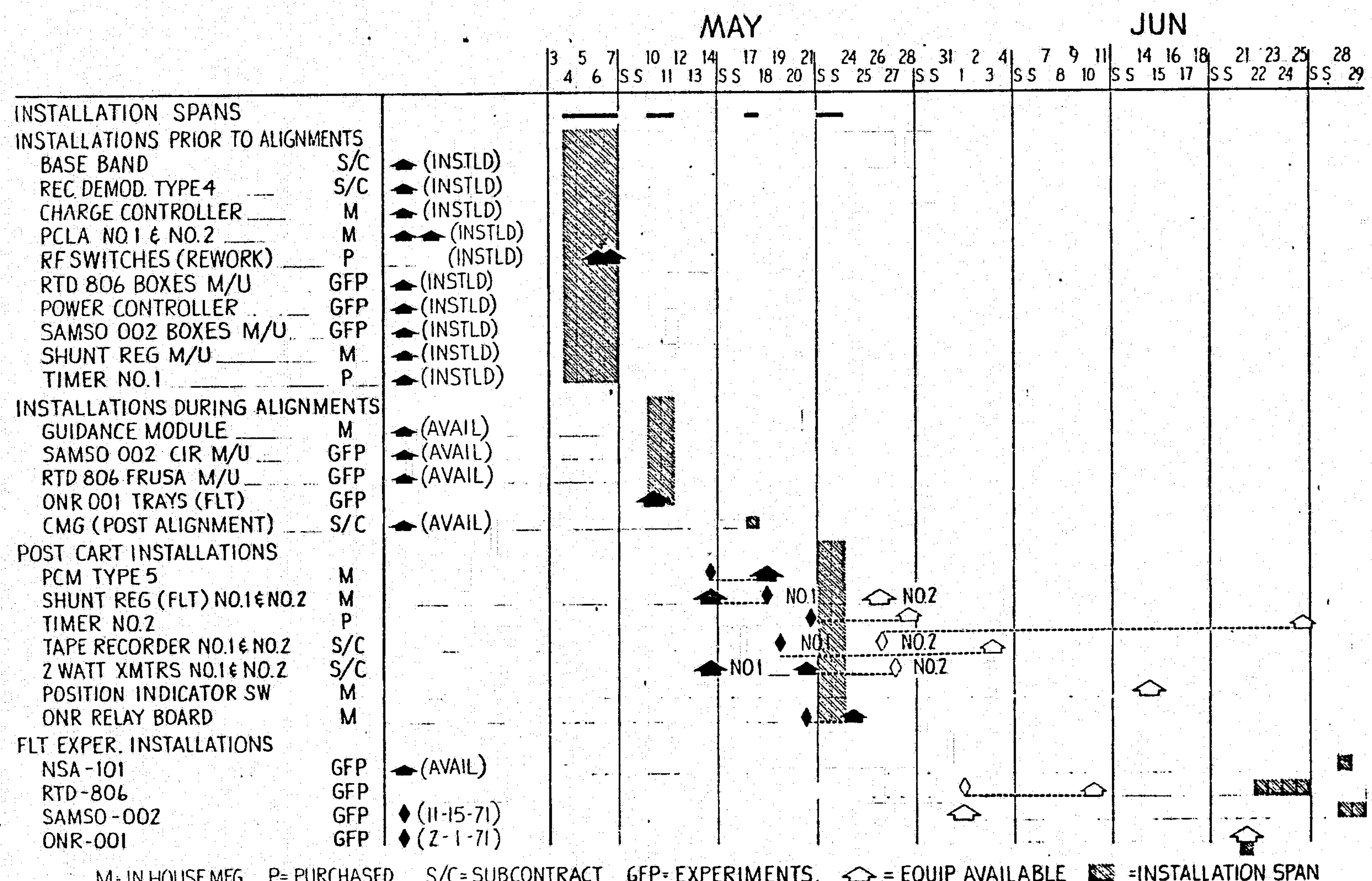

Fig 5-16 – SESP 71-2 Equipment Installation

The system level integration costs in Fig. 5-14 do not include the integration costs of $564.5K which were allocated to subsystems, GSE, and spacecraft test equipment (STE). These are shown at the bottom of Fig. 5-14 with the system level integration cost added in, but excluding the physical final assembly integration costs.

.5.3.5 System Reliability

With the exception of the minor reliability costs allocated to two TT&C black boxes and GSE, all the reliability costs were collected at the system level as shown in Fig. 5-17. The reliability costs include maintainability, safety, production, materials and process engineering, as well as the basic reliability functions.

.5.3.6 System Quality Assurance

The total SESP 71-2 quality assurance program cost of $1000.7K is shown in Fig. 5-18. Included in that total are costs allocated to subsystems and extensive system test support. If these allocated items are deducted, the remaining system level Q.A. cost is $309.6K as shown at the bottom of Fig. 5-18. The Q.A. functions identified are as shown in the figure. Also shown are the Q.A. documentation and report costs which could be isolated.

.5.3.7 Spacecraft Test Equipment

The spacecraft test equipment (STE) costs were collected at the subsystem (black box) level and at the total system level. The system level STE costs consisted of modifying the existing Sunnyvale C-7 test complex STE, experiment STE, and overall STE integration and support. Fig. 5-19 shows the SESP 71-2 system test AGE (referred to in this report as STE) activities and schedule.

Fig. 5-20 presents the SESP 71-2 System level STE costs of $595.2K. If the STE costs allocated to subsystems ($141.9K) are included, the total SESP program STE costs were $737.0 K. The STE allocated to subsystems, mostly at

BREAKDOWN	NON-RECURRING DESIGN & DEVEL. COSTS: LABOR Hours	LABOR Direct $	LABOR O/H $	ODC Pts & Mt'l $	ODC G&A & Other $	Total NR $	RECURRING 1st FLIGHT UNIT COSTS: LABOR Hours	LABOR Direct $	LABOR O/H $	ODC Pts & Mt'l $	ODC G&A & Other $	Total R $	Total $ NR & R
RELIABILITY & MAINTAINABILITY													
MANAGEMENT & CONTROLS	999	9.8	7.3	—	2.7	19.8	620	6.2	4.6		1.7	12.4	32.2
DOCUMENTATION	469	4.1	3.3		1.3	8.7	275	2.5	2.0		0.7	5.2	13.9
FAILURE MODE ANALYSIS	941	8.4	6.8		2.5	17.8	1145	10.2	8.2		3.1	21.5	39.3
PARTS SELECT. & SCREEN.	507	4.4	3.7		1.4	9.5	507	4.4	3.7		1.4	9.5	19.0
DESIGN REVIEWS	1867	16.5	13.5		5.0	35.0							35.0
MFG. SURVEILLANCE							389	3.1	2.9		1.1	7.1	7.1
S/C LAUNCH READY ANALYSIS							1408	11.7	10.7		3.9	26.3	26.3
QUAL TEST SUPPT.	2141	18.5	15.9		5.9	40.3							40.3
CONTAM./CORROSION CONTR.	65	0.7	0.5		0.2	1.3	92	0.9	0.7		0.2	1.8	3.1
SUBTOT.	6989	62.4	51.0	—	18.9	132.4	4436	39.0	32.7	—	12.1	83.8	216.2
SYSTEM SAFETY													
MANAGEMENT & CONTROLS	117	1.2	0.8		0.3	2.3							2.3
ANALYSES	377	3.6	2.6		1.0	7.3							7.3
DOCUMENTATION	104	0.8	0.8		0.3	1.9							1.9
S/C & LMSC AUDIT							128	1.0	1.0		0.4	2.4	2.4
SUBTOT.	598	5.7	4.2	—	1.6	11.5	128	1.0	1.0	—	0.4	2.4	13.8
PRODUCTION SYST. ENGRG.	1189	10.1	8.5	—	3.2	21.8	804	6.8	5.8	—	2.2	14.9	36.7
MATERIAL & PROCESS ENGRG.	28	0.2	0.2	—	0.1	0.5	—	—	—	—	—	—	0.5
ELECTROMAGNETIC COMPAT. ENGRG. & ANALYSIS	101	0.7	0.8	—	0.4	1.9	406	2.9	3.1	—	11.9	17.9	19.7
LIAISON ENGRG. & INTEGR.	302	2.2	2.0	—	0.8	5.0	302	2.2	2.0	—	0.8	5.0	10.0
RELIABILITY TRANSFERRED													
TO GSE	44	0.3	0.3		0.1	0.8							0.8
TO TT&C S/S	1765	10.9	12.7		5.9	29.5							29.5
SUBTOT.	1809	11.2	13.0	—	6.0	30.3	—	—	—	—	—	—	30.3
TOTAL RELIABILITY	11016	$92.5	$79.7	—	$31.0	$203.2	6076	$52.0	$44.6	—	$27.3	$123.9	$327.1
(TOT. HRS. = 17092)													
LESS RELIABILITY TRANSFERRED TO GSE & TT&C	1809	11.2	13.0	—	6.0	30.3	—	—	—	—	—	—	30.3
SYSTEM RELIABILITY	9207	$81.3	$66.7	—	$25.0	$173.0	6076	$52.0	$44.6	—	$27.3	$123.9	$296.9
(TOT. HRS. = 15,283)													

Note: $ may not add due to rounding; all $ in thousands of real year dollars.

Fig. 5-17 – SESP 71-2 System Reliability Costs

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BREAKDOWN	NON-RECURRING DESIGN & DEVEL. COSTS						RECURRING 1st FLIGHT UNIT COSTS						Total $ NR & R
	LABOR			ODC		Total NR $	LABOR			ODC		Total R $	
	Hours	Direct $	O/H $	Pts & Mt'l $	G&A & Other $		Hours	Direct $	O/H $	Pts & Mt'l $	G&A & Other $		
Q.A. PROGRAM MANAGEMENT	3645	30.3	27.1	—	8.8	66.2	2640	22.0	19.6	—	6.4	48.0	114.2
INSPECTION PLANS & LIAISON	1044	7.6	7.6	—	2.5	17.7	1078	7.5	7.9	—	2.6	17.9	35.6
PLANT SCREENING & AUDITS	659	4.7	4.7	—	1.6	11.0	447	3.2	3.2	—	1.0	7.4	18.4
PROCUREMENT SUPPORT													
RECEIVING TEST & INSPECT							1106	5.9	8.2		2.7	16.7	16.7
SOURCE PRODUCT VERIFICATION							3820	26.8	27.0		9.2	63.1	63.1
SUPPLIER QUAL. AUDITS							310	2.2	2.3		0.7	5.2	5.2
SUBSYSTEM PROC. SUPPORT*							3351	21.3	25.3		8.0	54.6	54.6
SUBTOT.	—	—	—	—	—	—	8587	56.2	62.8	—	20.6	139.6	139.6
Q.A. DOCUMENTATION & REPORTS													
AN&L TRACKING REPORTS	27	0.2	0.2		0.1	0.4	27	0.2	0.2		0.1	0.4	0.8
SUBCON./SOURCE DOCUMENT.	212	1.6	1.6		0.5	3.7	212	1.6	1.6		0.5	3.7	7.4
MFG. TEST DOCUM. REVIEW	1369	10.4	10.3		3.3	24.1	1369	10.4	10.3		3.3	24.1	48.1
VST DOCUMENTATION & DATA**							946	5.1	7.2		2.3	14.6	14.6
SUBTOT.	1608	12.2	12.1	—	3.9	28.2	2554	17.3	19.2	—	6.2	42.8	71.0
VEHICLE SYSTEM TEST SUPPT.**													
PLANNING & INSPECTION	373	3.0	2.9		0.9	6.8	373	3.0	2.9		0.9	6.8	13.6
CONTAMINATION CONT. INSP.							133	0.8	1.0		0.3	2.1	2.1
TEST COMPLEX INSPECT.							49	0.3	0.4		0.1	0.8	0.8
VST INSPECTION	727	4.4	5.6		1.8	11.7	4365	25.4	32.8		10.7	68.9	80.6
VEH. ACCEPT. TEST (VAFB)							535	4.1	4.1		1.3	9.5	9.5
" " " PROCEDURES	910	6.3	6.7		2.2	15.2	659	4.6	4.9		1.6	11.0	26.2
TEST FAILURE ANALYSIS							2862	19.8	21.9	0.1	11.5	53.2	53.2
SUBTOT.	2010	13.7	15.1	—	4.9	33.7	8976	58.0	67.9	0.1	26.5	152.3	186.0
SUBSYSTEM Q.A. SUPPORT*													
IN-PROCESS FACTORY TEST							6897	39.2	51.5		16.1	106.8	106.8
IN-PROCESS INSPECTION	1804	10.1	13.8		4.3	28.2	17169	93.6	126.6		43.4	263.6	291.8
DEV. & QUAL. TEST SUPPT.	1675	9.8	12.7		5.5	28.0							28.0
TOOL. & STE INSPECTION	509	2.7	3.7		1.3	7.7							7.7
FAILURE ANALYSIS	48	0.3	0.4		0.1	0.8	47	0.4	0.3		0.1	0.8	1.6
SUBTOT.	4036	22.9	30.6	—	11.2	64.7	24113	133.1	178.5	—	59.6	371.2	435.9
TOTAL Q.A. PROGRAM	13002	$91.4	$97.2	—	$32.8	$221.4	48395	$297.2	$359.1	$0.1	$122.9	$779.3	$1000.7
(TOT. HRS. = 61,397)													
*LESS ALLOCATED TO SUBSYST.	4036	22.9	30.6	—	11.2	64.7	27464	154.4	203.8	—	67.6	425.8	490.5
**LESS ALLOCATED TO SYST. TEST	2010	13.7	15.1	—	4.9	33.7	9922	63.1	75.1	0.1	28.8	166.9	200.6
SYSTEM Q.A. TOTAL	6956	$54.8	$51.5	—	$16.7	$123.0	11,009	$79.7	$80.3	—	$26.5	$186.6	$309.6
(TOT. HRS. = 17,965)													

Note: $ may not add due to rounding; all $ in thousands of real year dollars.

Fig 5-18 - SESP 71-2 System Quality Assurance Costs

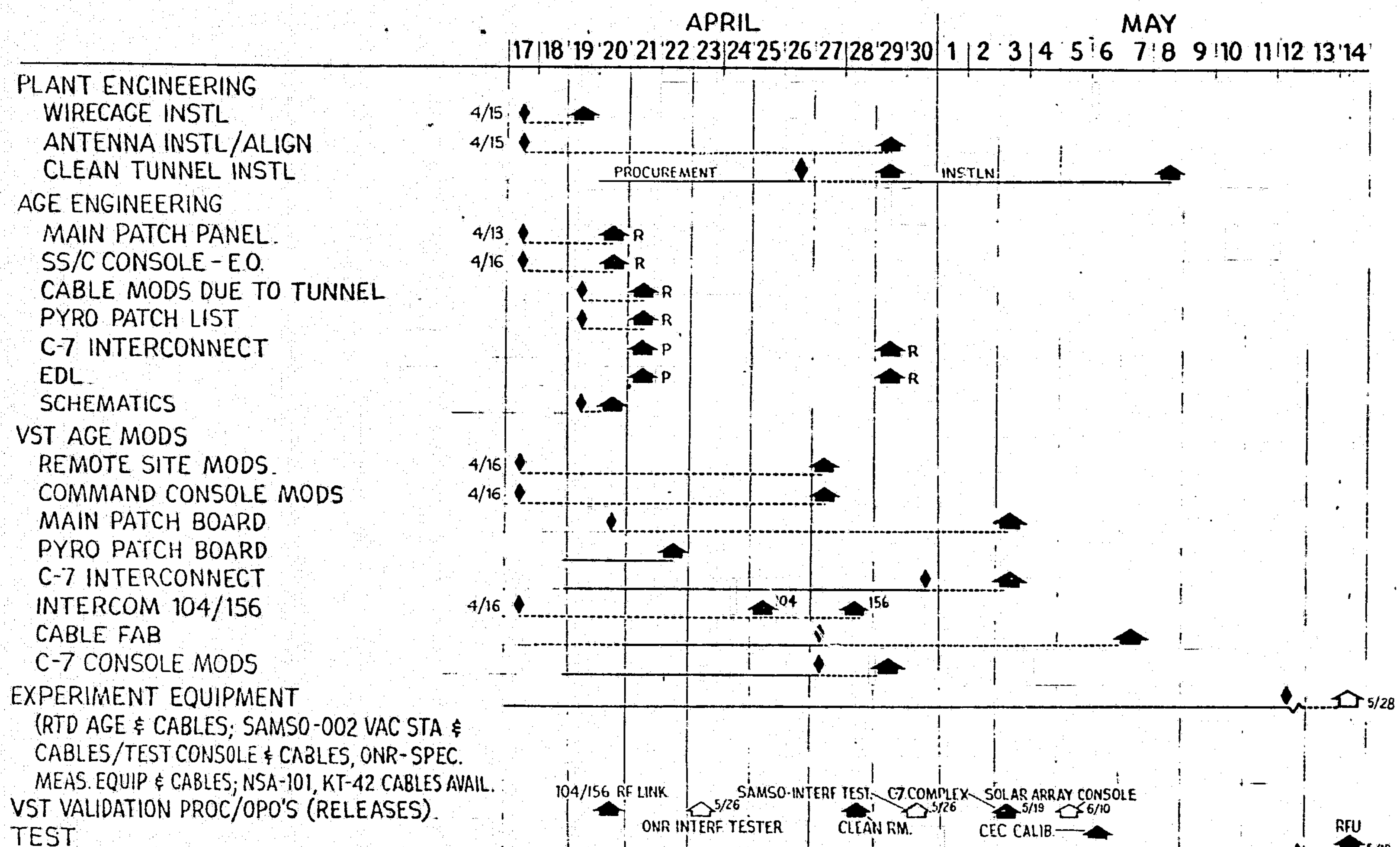

Fig 5-19 – SESP 71-2 System Test AGE (C-7)

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BREAKDOWN	NON-RECURRING DESIGN & DEVEL. COSTS						RECURRING 1st FLIGHT UNIT COSTS						Total $ NR & R
	LABOR			ODC		Total NR $	LABOR			ODC		Total R $	
	Hours	Direct $	O/H $	Pts & Mt'l $	G&A & Other $		Hours	Direct $	O/H $	Pts & Mtl $	G&A & Other $		
OVERALL													
PROGRAM MANAGEMENT	1749	12.3	12.7		7.3	32.3	76	0.6	0.6		0.4	1.6	33.9
INTEGRATION	1467	10.0	10.8		6.3	27.1	533	3.9	3.9		3.0	10.9	38.0
DESIGN SUPPORT	1376	9.3	10.0		3.5	22.8	104	0.7	0.8		0.3	1.7	24.6
TEST SUPPT. & VERIFICATION	1078	7.6	8.2		2.2	18.1	521	3.2	3.9		1.1	8.2	26.3
SUBTOT.	5670	39.3	41.7	—	19.3	100.4	1234	8.4	9.1	—	4.8	22.3	122.7
SYSTEMS TEST COMPLEX													
DESIGN - C&C EQ. MODS.	2155	13.3	16.2		4.4	33.9							33.9
" - AUX. EQ. SCHEMATICS	732	4.4	5.6		1.5	11.5							11.5
INTEGRATION	27	0.2	0.2		0.1	0.4							0.4
MFG.	1061	4.7	8.8	6.7	2.2	22.4							22.4
Q.A.	949	5.1	7.3		2.4	14.7							14.7
INSTALLATION & C/O	4831	28.0	36.9	0.3	10.0	75.2							75.2
SUBTOT.	9755	55.6	74.9	7.0	20.6	158.1	—	—	—	—	—	—	158.1
EXPERIMENT STE													
SAMSO-002 INTERFACE													
TESTER - DESIGN	1019	7.1	7.2		2.0	16.3							16.3
- MFG				3.7		3.7							3.7
- Q.A.	148	0.7	1.1		0.4	2.2							2.2
ONR-001 SIMULATOR DESIGN	294	1.7	2.2		0.6	4.5							4.5
- MFG.	921	4.3	7.6	4.4	1.9	18.3							18.3
- Q.A.	44	0.2	0.4		0.1	0.7							0.7
NSA-101 REMOTE SITE EQ. DESIGN	2589	19.5	19.3		4.3	44.1							44.1
- MFG.	423	2.0	3.5	8.0	0.9	14.4							14.4
- Q.A.	173	0.9	1.3		0.4	2.7							2.7
- INST. & C/O	5582	35.6	42.6		11.5	89.7							89.7
SUBTOT.	11193	72.0	85.1	16.2	23.1	196.5	—	—	—	—	—	—	196.5
SPACECRAFT STE													
SYSTEM TEST CABLES	2060	9.6	16.9	5.5	61.9	93.9	664	4.7	5.4	—	1.4	11.5	105.3
SUBSYSTEM STE - GENERAL													
TECH DIRECTION & CONT.	210	1.7	1.7		0.4	3.8							3.8
INTEGRATION	493	3.7	3.9		1.0	8.6							8.6
Q.A. INSPECTION	17	0.1	0.1			0.2							0.2
SUBTOT.	720	5.5	5.7	—	1.4	12.6	—	—	—	—	—	—	12.6

Note: $ may not add due to rounding; all $ in thousands of real year dollars.

Fig 5-20 (sheet 1 of 2) SESP 71-2 Spacecraft Test Equipment Costs

BREAKDOWN	NON-RECURRING DESIGN & DEVEL. COSTS						RECURRING 1st FLIGHT UNIT COSTS						Total $ NR & R
	LABOR			ODC		Total NR $	LABOR			ODC		Total R $	
	Hours	Direct $	O/H $	Pts & Mt'l $	G&A & Other $		Hours	Direct $	O/H $	Pts & Mtl $	G&A & Other $		
SUBSYSTEM STE													
TRANSFERRED TO SUBSYST.													
STRUCTURES STE - DESIGN	453	3.3	3.7	0.1	0.9	8.0							8.0
- MFG.	202	1.1	1.6		5.9	8.6							8.6
ELECTRICAL STE - DESIGN	755	5.5	5.4		1.5	12.4							12.4
- MFG.	2486	12.2	19.3	8.7	53.3	93.5							93.5
STAB. & CONT. STE - DESIGN	39	0.3	0.3		0.1	0.6							0.6
- MFG.	97	0.4	0.7		2.7	3.9							3.9
TT&C STE - DESIGN	144	0.9	1.0		0.5	2.4							2.4
- MFG.	558	2.6	3.9	2.6	1.1	10.2							10.2
EXPER. SUPPT. STE - DESIGN	74	0.5	0.6		0.1	1.2							1.2
- MFG.	26	0.1	0.2		0.8	1.1							1.1
SUBTOT.	4834	26.8	36.6	11.5	66.9	141.9	—	—	—	—	—	—	141.9
SUBSYSTEM STE TOTAL	5554	32.3	42.3	11.5	68.4	154.4	—	—	—	—	—	—	154.4
TOTAL STE	34,232	$208.8	$261.0	$40.2	$193.3	$703.2	1898	$13.1	$14.5	—	$6.1	$33.7	$737.0
(TOT. HRS. = 36,130)													
LESS STE TRANSFERRED TO SUBSYSTEMS	4834	26.8	36.6	11.5	66.9	141.9	—	—	—	—	—	—	141.9
SYSTEM STE TOTAL	29,398	$182.0	$224.4	$28.7	$126.4	$561.4	1898	$13.1	$14.5	—	$6.1	$33.7	$595.2
(TOT. HRS. = 31,296)													

Note: $ may not add due to rounding; all $ in thousands of real year dollars.

Fig 5-20 (sheet 2 of 2) SESP 71-2 Spacecraft Test Equipment Costs

BREAKDOWN	NON-RECURRING DESIGN & DEVEL. COSTS						RECURRING Ist FLIGHT UNIT COSTS						Total $ NR & R
	LABOR			ODC		Total NR $	LABOR			ODC		Total R $	
	Hours	Direct $	O/H $	Pts & Mt'l $	G&A & Other $		Hours	Direct $	O/H $	Pts & Mtl $	G&A & Other $		
OVERALL													
PROGRAM MANAGEMENT	686	5.1	5.0		3.9	14.0	51	0.4	0.4		0.3	1.0	15.1
INTEGRATION	607	4.5	4.5		3.5	12.4	355	2.6	2.6		2.0	7.2	19.7
DESIGN SUPPORT	917	6.2	6.7		2.3	15.2	69	0.5	0.5		0.2	1.2	16.4
MFG. PLANNING	880	5.2	7.1		1.8	14.1							14.1
SYST. ENG. & REQMNTS.	1959	15.5	14.2		5.9	35.6							35.6
TEST SUPPT. & LIAISON							299	2.7	2.3		0.6	5.6	5.6
RELIABILITY	44	0.3	0.3		0.1	0.8							0.8
SUBTOT.	5093	36.8	37.8	—	17.5	92.1	774	6.1	5.8	—	3.1	15.0	107.1
LAUNCH BASE (SLC-IN) EQUIP.													
DESIGN - EQUIP. MODS.	3765	24.6	28.5		7.7	60.8							60.8
MFG. - " "	934	4.8	7.7	25.8	1.9	40.2							40.2
Q.A. - " "	86	0.5	0.7		0.2	1.3							1.3
SUBTOT.	4785	29.8	36.9	25.8	9.9	102.4	—	—	—	—	—	—	102.4
GROUND HANDLING EQUIP.													
DESIGN (5 ITEMS)	764	5.9	5.4		1.5	12.7							12.7
MFG. "	938	5.6	7.3	1.3	1.9	16.0							16.0
Q.A. "	34	0.2	0.3		0.1	0.5							0.5
SUBTOT.	1736	11.6	12.9	1.3	3.5	29.3	—	—	—	—	—	—	29.3
SERVICE EQUIPMENT -													
COOLANT SERVICE UNIT													
DESIGN	149	1.1	1.1		0.3	2.5							2.5
MFG. & REPAIR	715	3.9	5.7	4.0	1.5	15.2	23	0.1	0.2		0.1	0.4	15.5
SUBTOT.	864	5.1	6.8	4.0	1.8	17.7	23	0.1	0.2	—	0.1	0.4	18.0
CONTAMINATION CONTROL													
DESIGN	128	0.9	1.0		0.3	2.1							2.1
MFG.	825	4.1	6.8	45.0	2.1	58.0							58.0
SUBTOT.	953	5.0	7.8	45.0	2.3	60.1							60.1
SPARES	—	—	—	—	—	—	7	—	0.1	7.4	—	7.5	7.5
LAUNCH OPS. SUPPT.	—	—	—	—	—	—	71	0.5	0.6	—	0.1	1.2	1.2
GSE TOTAL	13,431	$88.4	$102.1	$76.1	$34.9	$301.5	875	$6.8	$6.6	$7.4	$3.3	$24.1	$325.6
TOT. HRS. = 14,306													

Note: $ may not add due to rounding; all $ in thousands of real year dollars.

Fig 5-21 - SESP 71-2 Ground Support Equipment Costs

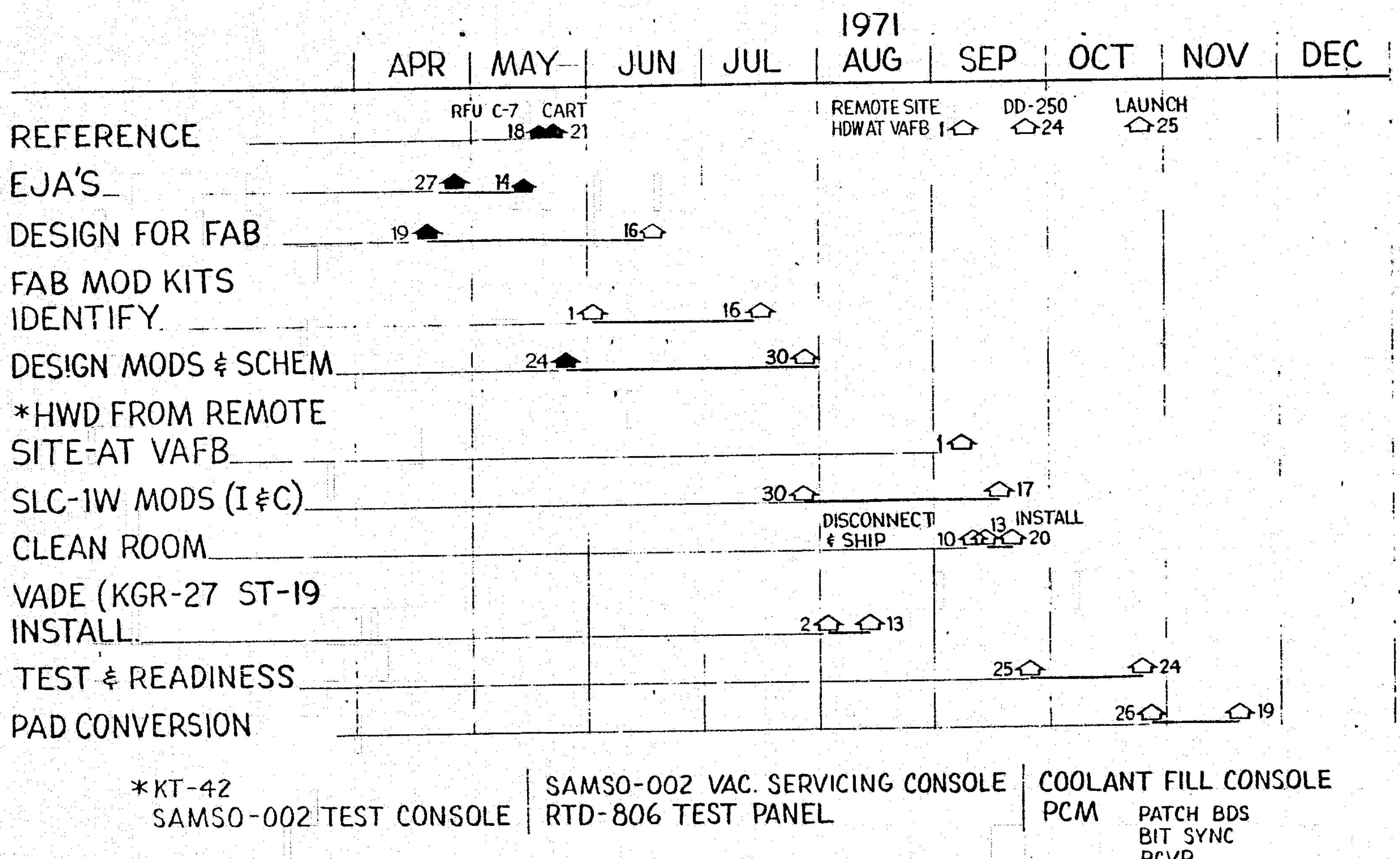

Fig 5-22 SESP 71-2 Launch Base Age

BREAKDOWN	NON-RECURRING DESIGN & DEVEL. COSTS						RECURRING 1st FLIGHT UNIT COSTS						
	LABOR			ODC		Total NR $	LABOR			ODC		Total R $	Total $ NR & R
	Hours	Direct $	O/H $	Pts & Mt'l $	G&A & Other $		Hours	Direct $	O/H $	Pts & Mtl $	G&A & Other $		
REPAIR & MAINTENANCE OF SPARES							114	0.6	0.9	25.1	0.2	26.9	26.9
INSPECTION OF SPARES							140	0.7	1.1	—	0.3	2.1	2.1
MISC. COMPONENT FAB.							28	0.1	0.2	0.1	0.6	1.0	1.0
SYSTEM SPARES TOTAL *	—	—	—	—	—	—	282	$ 1.4	$ 2.2	$ 25.2	$ 1.2	$ 30.0	$ 30.0
* EXCLUDES:													
ELECTRICAL S/S SPARES							241	1.1	2.0	30.6	0.6	34.3	34.3
TT&C S/S SPARES							—	—	—	124.3	—	124.3	124.3
GSE SPARES							7	—	0.1	7.4	—	7.5	7.5
TOTAL ALLOCATED SPARES	—	—	—	—	—	—	248	1.1	2.1	162.3	0.6	166.1	166.1
SPARES GRD. TOTAL	—	—	—	—	—	—	530	$ 2.6	$ 4.2	$ 187.5	$ 1.8	$ 196.1	$ 196.1

Note: $ may not add due to rounding; all $ in thousands of real year dollars.

Fig. 5-23 - SESP 71-2 System Spares Costs

BREAKDOWN	NON-RECURRING DESIGN & DEVEL. COSTS						RECURRING 1st FLIGHT UNIT COSTS						Total $ NR & R
	LABOR			ODC		Total NR $	LABOR			ODC		Total R $	
	Hours	Direct $	O/H $	Pts & Mt'l $	G&A & Other $		Hours	Direct $	O/H $	Pts & Mtl $	G&A & Other $		
LAUNCH OPS. SUPPORT													
TEST PERSONNEL							57	0.4	0.4		0.1	1.0	1.0
GSE "							71	0.5	0.6		0.2	1.2	1.2
SUBSYSTEM " - PRE LAUNCH	136	1.1	1.0		0.3	2.4	1215	10.2	9.3		2.5	22.0	24.4
SUBSYSTEM " - POST LAUNCH							3031	25.3	23.6		6.4	55.2	55.2
SUBTOT.	136	1.1	1.0	—	0.3	2.4	4374	36.4	33.9	—	9.2	79.4	81.8
HANDLING & SHIPPING													
PACK. & TRANSPORT ENG.	416	2.6	3.4		0.9	6.9	122	0.9	1.0	0.6	0.3	2.7	9.6
PREP. VEH. FOR SHIPMENT							255	1.6	2.0		0.8	4.3	4.3
SUBTOT.	416	2.6	3.4	—	0.9	6.9	377	2.5	3.0	0.6	1.0	7.0	13.9
PROGRAM LAUNCH OPS. SUPPT.													
RTA-806 DATA PROCESSING							1162	11.1	9.9	7.9	11.8	40.8	40.8
SAM10-002 " "							1992	16.3	12.9	6.2	19.9	55.4	55.4
ENR-001 " "							2141	19.9	19.0		22.4	61.4	61.4
EXTENDED ORBIT SUPPT.							1562	14.4	13.6		17.2	45.2	45.2
SUBTOT.	—	—	—	—	—	—	6857	61.7	55.4	14.2	71.3	202.6	202.6
LAUNCH OPS. & SUPPT. TOTAL (TOT. HRS. = 12,160)	552	$3.7	$4.5	—	$1.1	$9.3	11608	$100.6	$92.2	$14.7	$81.5	$289.0	$298.4
LESS ALLOCATED TO SUBSYSTEMS	136	1.1	1.0		0.3	2.4	4246	35.5	32.8	—	8.9	77.2	79.7
LESS " TO GSE							71	0.5	0.6	—	0.2	1.2	1.2
SYSTEM LAUNCH OPS. & SUPPT. (TOT. HRS. = 7707)	416	$2.6	$3.4	—	$0.9	$6.9	7291	$64.6	$58.8	$14.7	$72.5	$210.6	$217.5

Note: $ may not add due to rounding; all $ in thousands of real year dollars.

Fig. 5-24 - SESP 71-2 Launch Operations and Support Costs

the black box level, represented manufacturing test equipment used to test the various components and boxes during manufacturing process.

.5.3.8 Ground Support Equipment

The SESP 71-2 vehicle, being a modified Agena spacecraft, benefitted from extensive existing ground support equipment (GSE). This high GSE inheritance is reflected in the costs shown in Fig. 5-21. The GSE costs are broken down by launch base equipment, ground handling equipment, servicing equipment, contamination control equipment, and overall program GSE support costs.

The launch base equipment consisted of minor modifications of existing consoles and GFE equipment. The ground handling equipment consisted of new and modified items. The servicing and contamination control equipment was new. In total, GSE costs were minor at $325.6K as shown.

Fig. 5-22 shows the schedule and major activities associated with the launch base AGE (referred to in this report as GSE).

.5.3.9 System Spares

The SESP 71-2 vehicle and GSE spares were minimal consisting of one tape recorder, some batteries, and parts for critical black boxes. The total spares cost including subsystem and GSE spares was $196.1K. Out of this total $166.1K of spares cost was allocated to electrical and TT&C subsystems and GSE as shown in Fig. 5-23. The system level spares represent the remaining $30K consisting primarily of spares repair and maintenance cost.

.5.3.10 Launch Operations and Support

The program launch operations and support costs are presented in Fig. 5-24. The total SESP cost including 13 plus months of on orbit flight support was $298.4K. The launch operations and support costs allocated previously to subsystems and GSE were $81.8K resulting in systems level charges of $217.5K as shown at the bottom of Fig. 5-24.

The SESP 71-2 launch base activities and schedule are indicated in Fig. 5-25. LMSC responsibilities as the SESP 71-2 integrating contractor were limited to providing operational technical assistance and support services to launch activities performed by others. The Thorad booster was the responsibility of McDonnell Douglas. LMSC/VAFB had the launch services contract. Aerospace Test Wing 6595 had the launch responsibility and A. F. Satellite Control Facility provided tracking, telemetry, and command services.

6.0 SESP 71-2 COST PERCENTAGE DISTRIBUTIONS

The SESP 71-2 program costs as allocated are summarized in Fig. 6-1. Also shown are percentage distributions derived in terms of manhours, as well as dollars for the total program costs. Fig. 6-2 shows these costs in terms of basic accounting cost categories and their percentage distributions.

Utilizing the total SESP 71-2 costs for some of the selected functions, including the portions which have been allocated to subsystems, Fig. 6-3 was prepared. It attempts to show the maximum cost and percentage of program cost for a given function if all the buried costs are summarized under a given function. Only functions thought to be of special interest are shown and there are cost overlaps.

For example maximum quality assurance cost of $1000.7K or 8.3% max. of program cost includes Q. A. system test support of $200.6K charged to system test. (See Fig. 5-18). The maximum cost of $937.1K for test function shown in Fig. 6-3 includes the above Q. A. support and test costs allocated to subsystems, in addition to the system test costs shown in Fig. 5-12.

Another function of interest is system integration. Considering only the "software" costs, excluding the physical hardware final assembly costs, the maximum integration costs identified in the SESP program including subsystems charges were $699K (See Fig. 5-14) or 5.8% of program cost and 11.6% of program in-plant manhours. Combining "software" system integration function with system engineering function, the maximum estimated cost to SESP becomes 17.3% of program cost and 21.3% of in-plant manhours.

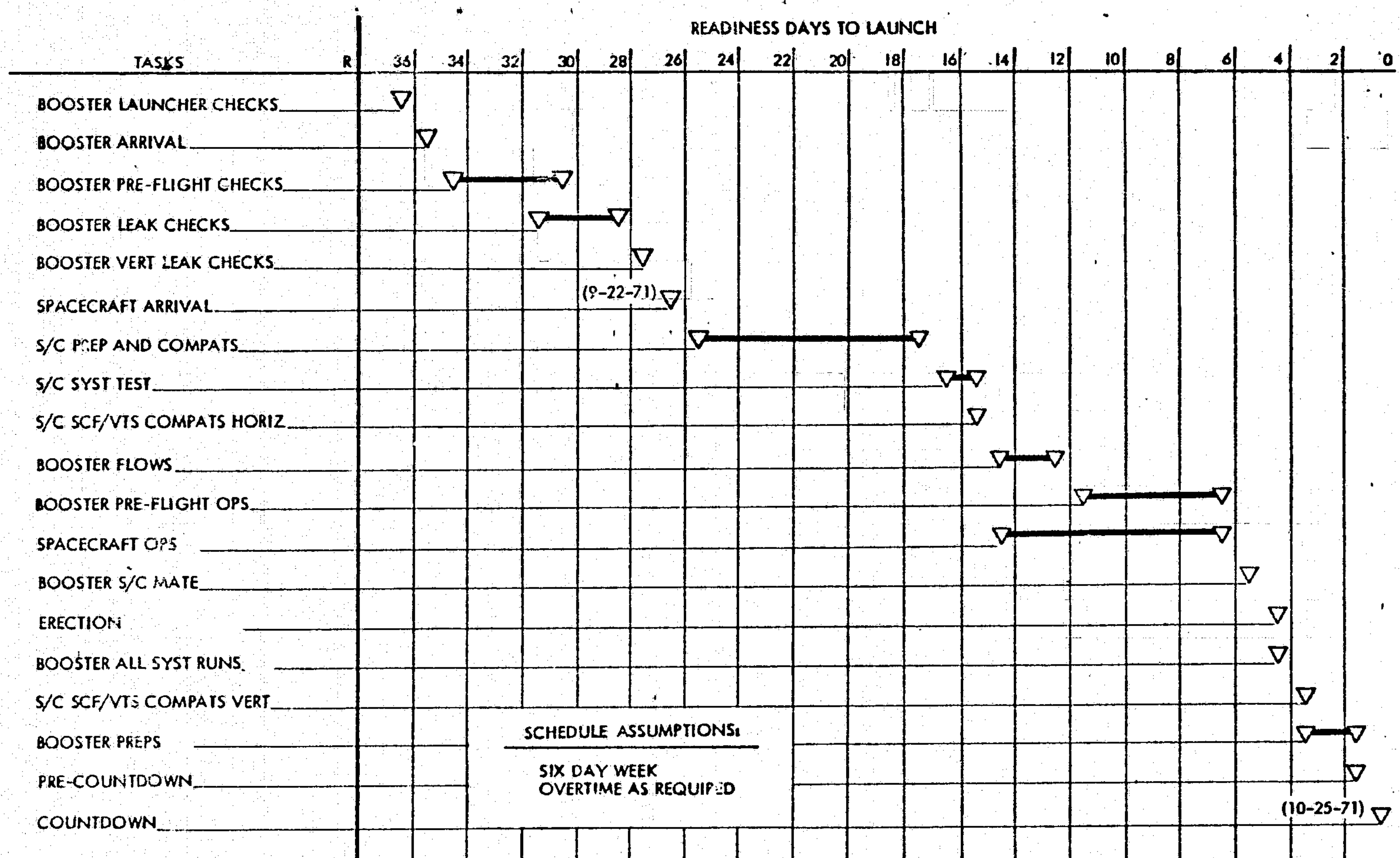

Fig 5-25 - SESP 71-2 Launch Base Activity

BREAKDOWN	Non-Recurring Hours	Non-Recurring $K	Recurring Hours	Recurring $K	Total Hours	Total $K	% Distrib. Hrs.	% Distrib. $
Structures	40957	$ 723.0	41536	$ 854.8	82493	$ 1577.8	15.5	13.1
Thermal Control	7834	149.7	407	17.7	8241	167.3	1.5	1.4
Propulsion	1646	27.9	4565	445.0	6211	472.9	1.2	3.9
Electrical Power	36619	660.8	33568	779.2	70187	1440.0	13.2	12.0
Stabilization and Control	11384	196.4	10214	470.3	21598	666.7	4.1	5.5
TT&C	39892	876.2	26839	1579.9	66731	2456.2	12.6	20.4
Experiment Supt. Equip.	10679	235.4	2461	45.3	13140	280.7	2.5	2.3
Subsystems	149011	$2869.4	119590	$4192.2	268601	$ 7061.6	50.6%	58.7%
Prog. Mgm't and Data	15576	341.9	10788	242.1	26364	584.0	5.0	4.9
System Engineering	53765	950.6	20417	392.0	74182	1342.6	14.0	11.2
System Test	14356	236.5	36129	597.8	50485	834.3	9.5	6.9
Sys. Integration & Final Assy.	4928	93.8	19580	334.6	24508	428.4	4.6	3.6
Reliability	9207	173.0	6076	123.9	15283	296.9	2.9	2.5
Quality Assurance	6956	123.0	11009	186.6	17965	309.6	3.4	2.6
STE	29398	561.4	1898	33.7	31296	595.2	5.9	4.9
GSE	13431	301.5	875	24.1	14306	325.6	2.7	2.7
Spares & Logistics	-	-	282	30.0	282	30.0	-	0.2
Launch Ops. & Supt.	416	6.9	7291	210.6	7707	217.5	1.4	1.8
System	148033	$2788.6	114345	$2175.4	262378	$ 4964.0	49.4%	41.3%
Total Program Cost (1970-71 $)	297044	$5658.0	233935	$6367.6	530979	$12025.6	100.0%	100.0%

Fig. 6-1 - SESP 71-2 Program Cost Summary

Accounting Cost Categories	Non-Recurring		Recurring		Total	
	$X1000's	%	$X1000's	%	$X1000's	%
Direct Labor	2119.3	37.4	1554.2	24.4	3673.5	30.5
Overhead	2184.2	38.6	1779.4	28.0	3963.6	33.0
Parts, Material & Subcontract	348.4	6.2	2280.3	35.8	2628.7	21.9
G&A and Other	1006.1	17.8	753.7	11.8	1759.8	14.6
Total Cost	$5658.0	100.0	$6367.6	100.0	$12025.6	100.0

Fig. 6-2 SESP 71-2 - Basic Cost Category Distribution

Selected Functions	Max. % of Total Program			
	Hours		Cost ($X1000)	
Quality Assurance	61397	11.6	1000.7	8.3
Test	54689	10.3	937.1	7.8
Syst. Integration	36983	7.0	699.0	5.8
Syst. Engineering	76141	14.3	1378.2	11.5
SI & SE Combined		21.3		17.3
Reliability	17092	3.2	327.1	2.7
Mfg. Plan & Tooling	19712	3.7	313.3	2.6
Support Hdw.				
STE	36130	6.8	737.0	6.1
GSE	14306	2.7	325.6	2.7
Combined		9.5		8.8
Spares	-	-	196.1	1.6

Fig. 6-3 - Selected Functional Areas - SESP 71-2

The costs identified with spacecraft test equipment (STE), both at the system and subsystem level, represent 6.1% maximum of SESP program cost. Including GSE with STE costs results in 8.8 maximum percentage of program cost as shown in Fig. 6-3.

These percentage figures are considerably higher than the percentages shown for these functions in Fig. 6-1, where subsystems were allocated a substantial portion of costs for some functions. From the standpoint of program to program comparisons, care has to be taken in extracting total costs for a given function or comparable allocated cost share.

Lockheed Missiles & Space Company

LCPP-11

ENGINEERING MEMORANDUM

TITLE:	EM NO: LCPP-11
Space Experiments Support Program 71-2, Program Practices Analysis	REF: DATE: 15 May 1975
AUTHORS:	APPROVAL:
Jolanta B. Forsyth	ENGINEERING SYSTEM ENGRG D L Hannaford

INTRODUCTION

Lockheed Missiles and Space Company is currently performing the Low-Cost Program Practices study for NASA Headquarters under contract No. NAS W-2752. The principal objective of the study is to identify those NASA space program practices that contribute significantly to program costs. The Air Force Space Experiments Support Program 71-2 (SESP 71-2) has been identified as a low-cost program. The SESP 71-2 program costs have, therefore, been analyzed to determine the impact of various program practices on the costs of a typical unmanned, automated spacecraft program. The results of the analyses are presented in this engineering memorandum.

EM No. LCPP-11
Date: 15 May 1975

SPACE EXPERIMENTS SUPPORT PROGRAM 71-2
PROGRAM PRACTICES ANALYSIS

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SESP 71-2 PROGRAM PRACTICES ANALYSIS

This discussion of low-cost and high-cost program practices identified from the SESP 71-2 program history is subdivided into three parts to facilitate analysis. The three parts consist of: 1) inheritance, 2) practices besides inheritance, impacting the non-recurring cost and 3) practices impacting the recurring unit cost. The recurring operations practices were not studied.

11.1 INHERITANCE

Exploitation of inheritance from prior programs constitutes a major low-cost practice resulting in significant program cost savings or more programs/benefits for the same amount of dollars. Spacecraft program inheritance varies depending on: 1) the degree of off-the-shelf design applied; 2) amount of flight qualified hardware used; 3) the extent of existing software, test equipment, ground support equipment; and in some instances, 4) existence of facilities.

Use of inheritance has been implemented as a practice in many spacecraft programs, therefore it is not a new practice. However, the amount of cost savings achieved with this practice is highly dependent on the degree to which inheritance is implemented.

In the case of SESP 71-2, the degree of inheritance was very high. Fig. 1-1 shows the SESP spacecraft major assembly and black box status in terms of existing design and program peculiar design (modified or new equipment). From this approximate measure, 63% of the spacecraft was of existing design, 24% was modified equipment, and 13% was new. These figures are somewhat misleading, since some of the assemblies such as structures may have been of a new design but were not functionally critical to the mission and, therefore, did not represent the same cost implications as new active critical components. The latter require considerably higher investment in development, qualification

SUBSYSTEM	EXISTING DESIGN	NO. MAJOR ASSEMBLIES/BLACK BOXES — PROG. PECULIAR DESIGN — MODIFIED — NOT CRITICAL	MODIFIED — MISSION CRITICAL	NEW — NOT CRITICAL	NEW — MISSION CRITICAL
STRUCTURES	7	2	-	4	-
THERMAL	1	-	-	-	1
ELECTRICAL POWER	20	7	4	4	-
STABILIZATION & CONTROL	16	5	-	-	-
TT&C	16	6	5	2	3
PROPULSION	18	-	-	-	-
EXPER. SUPPT. EQ.	-	1	-	-	2
TOTAL S/C	78	21	9	10	6
% OF TOTAL	63%	17%	7%	8%	5%

Fig. 1-1 SESP 71-2 Spacecraft Inheritance Status

hardware, and testing. The last column in Fig. 1-1 lists the six new mission critical items which had not been flown previously. This 5% of equipment constituted the major SESP 71-2 development and test hardware cost. These items were: pulse code modulation unit type 5 (PCM-5), experiment interface unit type 1 (EIU-1), antenna type 28, heat exchanger coolant system, and two items supporting the experiments (RTD-806 array release mechanism and shaft position indicator). The modified mission critical equipment development (7% of the spacecraft boxes/assemblies) was concentrated in the tape recorder and other TT&C black boxes and the electrical power subsystem boxes.

Contributing to the extensive SESP 71-2 spacecraft hardware inheritance was the high support equipment inheritance represented by existing GSE and test equipment. An approximate count of support equipment shows, 23% were new with more than half of these being in the ground handling equipment category and therefore relatively inexpensive. The existing equipment comprised about 45%, the modified equipment about 29%, and GFE 3% of the items. Most of the expensive launch complex GSE was existing, and the test equipment complex required primarily minor modifications.

Software can be a considerable development cost driver. On the SESP 71-2 program, software was existing (only $12K was spent on it).

In summary, the impact of inheritance as a low-cost practice implemented in the SESP 71-2 program is shown in Figure 1-2. It is difficult to estimate precisely the dollar savings contribution of inheritance. This figure shows the results of ROM parametric cost estimates derived for a spacecraft with SESP 71-2 performance and mission characteristics. Considering the case with no inheritance, development "from scratch," $55M and $36M non-recurring development costs were estimated for the conventional development approach and the low-cost approach, respectively. The parametric estimates for the high inheritance case resulted in $9M to $6M non-recurring cost, allowing an estimated cost savings due to inheritance in the $46 to $30 million range depending upon the development approach.

CHARACTERISTICS:

- OFF-THE-SHELF DESIGN
- USE OF FLIGHT QUALIFIED HARDWARE
- EXISTING SOFTWARE, TEST EQUIPMENT & GSE

SESP 71-2 PROGRAM:

- ONLY SIX NEW ITEMS (5%) NOT FLOWN PREVIOUSLY
- MIN. DEVEL. & QUAL. TEST HARDWARE - COST $\approx$ \$350K
- USE OF EXISTING STE & GSE - COST $\approx$ \$900K

ESTIMATED COST IMPACT OF SESP INHERITANCE:

COSTS	CONVENTIONAL APPROACH	LOW COST APPROACH	DIFFERENCE DUE TO LOW COST PRACTICES
DEVELOPMENT "FROM SCRATCH"	\$55M	\$36M	\$19M
DEVELOPMENT WITH HIGH INHERITANCE	9	6	\$ 3M
INHERITANCE SAVINGS	\$46M	\$30M	

SESP 71-2 ACTUAL NR COST \$5.66M

Fig. 1-2 Major Low Cost Practice: Inheritance

The SESP 71-2 actual non-recurring development cost was \$5.66M, which is close to the low-cost approach estimate of \$6M and over \$3M lower than the conventional approach estimate with high inheritance. Since SESP 71-2 was built of conventional spacecraft hardware, it did implement low-cost practices beyond inheritance to reduce its non-recurring cost below the expected high inheritance, conventional spacecraft level.

11.2 SESP 71-2 PRACTICES WHICH PRIMARILY IMPACTED THE NON-RECURRING COST

The major practices, as identified from the SESP 71-2 history and financial records, which impacted primarily the SESP 71-2 non-recurring cost are listed in Fig. 2-1. Since, in many cases, the historical records do not provide the actual costs at the level of detail required, estimates had to be generated to provide some quantification of the practice.

The following discussion describes each practice in detail, both the high and the low-cost, and the means of estimating where actuals were not available.

11.2.1 Low-Cost Practice: Overdesigned Structure

Impact: SESP 71-2 NR Cost Savings Estimated at \$120K

Description:

Overdesign of the structure permitted elimination of the qualification test, and spacecraft bending moment and loads analyses were not required. The estimated cost savings of \$70K for the testing and \$50K for the analyses are based on analogous activities on other programs.

Conclusion:

Structures overdesigned by margins of several factors of safety do not require detailed strength testing and subsequent analyses. Such design and test practices for structures have been advocated by the previous LMSC Low-Cost Payload Studies as a part of low-cost design approach.

LOW-COST PRACTICES		EST. SAVINGS (70-71$)
DESIGN & TEST:		
o STRUCTURE OVERDESIGNED, NOT REQUIRING:		
QUALIFICATION TEST		$ 70K
S/C BENDING MOMENT & LOADS ANALYSES		50K
o SYSTEM THERMAL VACUUM TEST NOT REQUIRED		600K
o EMC TEST OF NEW COMPONENTS ONLY		N.A.
	SUBTOTAL	$720K
DOCUMENTATION:		
o MIL-D-1000 FORM 3 DRAWINGS		$400K
o USE OF EXISTING PROCEDURES, SYSTEMS & DOCUMENTATION		200K
o DELETION OF TWO CDRL ITEMS		10K
	SUBTOTAL	$610K
PROGRAMMATIC/MANAGEMENT:		
o SHORT (11 MOS.) DEVELOPMENT SPAN (EST. 5 MOS. SAVINGS OF ENG. & PROG. SUPPORT AT $300K/MO.)		$1500K
o MINIMUM IN SCOPE CHANGES (CONSIDERABLY LESS THAN AVERAGE NASA FOLLOW-ON S/C)		500K
	SUBTOTAL	$2000K
HIGH COST PRACTICES		
o FIRST TAPE RECORDER SUBCONTRACTOR COULD NOT MEET SPECS		-$174K
o LATE GFE EXPERIMENT SPECS CAUSED P/L MODULE REDESIGN		- 90K
o STRINGENT CONTAMINATION CONTROL REQUIREMENTS		- 65K
	SUBTOTAL	-$329K
NET LOW-COST PRACTICES NR SAVINGS		$3000K

Fig. 2-1 Practices Impacting SESP NR Cost

11.2.2 Low-Cost Practice: Eliminate System Thermal Vacuum Test

Impact: SESP 71-2 NR Cost Savings of $608K

Description:

System thermal vacuum test initially considered as required was eliminated at a cost savings of $608K (as quoted to the customer).

Conclusion:

The above savings, as well as the other test savings shown in Fig. 2-1, resulted in about $720K cost reduction which represents almost 5% savings of the hypothetical program cost. The program cost savings are discussed in Section .4.

11.2.3 Low-Cost Practice: Reduce and Simplify Documentation Requirements

Impact: SESP 71-2 Estimated NR Cost Savings of $610K

Description:

SESP 71-2 utilized MIL-D-1000 Form 3 drawings which represent 43% savings over the Form 2[1] commonly applied in LMSC AF programs. Based on a nominal program Form 2 drawing cost of $2.24M[2] of which 63% are assumed to be existing drawings (Fig. 1-1), about $400K savings can be derived from Form 3 application. ($2.24M + $1.72M simple changes x .37 x .43 x 16/22 ≈ $400K. The 16 ÷ 22 is the inflation adjustment to 1970-71 SESP 71-2 manhour rates.)

The use of existing procedures, systems, and engineering documentation (specifications, etc.) was estimated to save $200K. The $10K savings resulted from deletion of two specific CDRL items.

References: (1) PER Handbook, Appendix 1 to Final Report Low Cost Program Practices for Future NASA Space Programs, LMSC-D387518, 30 May 1974, p. 3-29.

(2) Op. cit., p. 3-25.

Conclusion:

Documentation costs are extensive and well hidden in the other costs of the program, primarily labor. Thus reduction of the papermill and simplification such as Form 3 vs. Form 2 drawings brings substantial savings. In the case of SESP 71-2 the estimated $610K savings represented about 4% program cost savings (see Fig. 4-1).

11.2.4 Low-Cost Programmatic and Management Practices

Impact: High. For SESP 71-2 this impact was estimated very ROM to be $2M.

Description:

The two practices with high cost impact considered under the programmatic/ management practice areas were the development time span and the number of in-scope changes.

The development time span has a significant impact on costs, because the longer a team is on a project the higher the labor costs. The development span for SESP 71-2 was 11 months maximum (the final design review) and could be considered as short as 8 months at which time engineering was 75% complete and final assembly had been started. The total time span from go-ahead to launch was 18.5 months, which is about 9 months shorter than some NASA programs with medium to high inheritance. For example:

OSO-F	18 months till delivery (launch, 12 + mos. later due to late experiements)
NIMBUS-E	31 months till launch
MM'71	31 months till launch
MVM'73	29 months till launch
Pioneer F	29 months till launch
Average	27.5 months till launch

The contribution of the SESP 71-2 short development span to savings of NR cost was estimated to be about $1.5M on the basis of an assumed additional 5 months of effort (27.5 ÷ 18.5 x 11 mos.) at the average SESP 71-2 rate of expenditure of $300K per month for engineering and program support efforts.

The cost impact of in-scope changes has been identified in a previous study (see Reference 1) as contributing significantly to program cost growth. In the SESP case the low number of in-scope changes contributed about 14% to cost growth, which is considerably less than NASA follow-ow spacecraft contracts averaging 25%.

The resultant cost savings are difficult to isolate since there exists an overlap with degree of inheritance and development time span. The arithmetic computation of savings was reduced by half to provide a conservative ROM estimate of $500K as savings attributed to small number of in-scope changes.

Conclusion:

Development time span and in-scope changes are very significant cost driving practices, and should be given thorough analysis in the program planning stages.

11.2.5 High Cost Practices Impacting SESP 71-2 NR Cost

Impact: The three specific practices identified caused dissavings of about $330K.

Description:

The three practices costly to the SESP 71-2 development were:

1) The original tape recorder subcontractor could not meet the design specifications and the subcontract was terminated at a $174K cost to the program.

2) Late definition of one of the GFE experiment specifications and the related requirements imposed on the spacecraft caused major payload module redesign effort at an estimated cost of $90K.

3) Very stringent contamination control requirements imposed by one of the GFE experiments were estimated to add about $65K to the cost of the program.

Conclusions:

These three practices caused dissavings of over 2% of the hypothetical program cost as estimated in Fig. 4-1.

II.3 PRACTICES IMPACTING SESP 71-2 UNIT COST

The practices impacting SESP 71-2 unit cost are summarixed in Fig. 3-1. Again both low-cost and high-cost practices were identified. These are discussed and quantified individually in the following sections.

II.3.1 Low-Cost Practice:. Existing Equipment Reuse

Impact: SESP 71-2 Unit Cost Savings of $371K

Description:

Reuse of existing Agena hardware available from other A.F. and NASA programs in the form of a DTV, black-box test or spares hardware, and common equipment inventory. This equipment became GFE to the SESP program, with the program paying for equipment refurbishment if any was required. The cost savings to the program were $371K and 5381 manhours.

	EST. SAVINGS (70 - 71$)
LOW COST PRACTICES:	
o EXISTING EQUIPMENT REUSE (REFURB. OR GFE)	$ 370K
o MINIMUM SPARES (TAPE RECORDER, 3 BATTERIES & PIECE PARTS)	400
o TEST HARDWARE UPGRADING TO FLIGHT HARDWARE	100
o QUANTITY BUY OF EQUIPMENT	30
SUBTOTAL	$ 910K
HIGH COST PRACTICES:	
o EXTENSIVE SYSTEM TEST (LATE GFE EXPERIMENTS & REPEATED TEST)	$-240K
AND ASSOCIATED SUPPORT COSTS	-220
o IN-HOUSE MAKE VS. BUY (PCM-5)	-200
SUBTOTAL	$-660K
NET LOW-COST PRACTICES UNIT SAVINGS	≈ $ 250K

Fig. 3-1 Practices Impacting SESP Unit Cost

REUSED & GFE EQUIPMENT - MAJOR ITEMS BY SUBSYSTEM:

Subsystem	Equipment	Cost to SESP	Est. New Cost	Savings
S & C	Guidance Module	$123K	$350K	
	Flight Controls	46	75	
	ACS N_2 Tank & Plumbing	-	16	
	N_2 Regulator	-	9	
	Thrust Valve Cluster	13	18	
	Total	$182K	$468K	$286K
TT&C	Antenna Type 7	-	2	
	Magnetic Timers	-	3	
	RF Switches	-	1	
	Total	-	$ 6K	$ 6K
Electrical	Power Distribution J-Box	5	11	
	Fwd. Safe/Arm Box	1	2	
	Inverter	-	17	
	Main Pwr. Tr. Switch	-	4	
	Amp. Hr. Meters	-	2	
	DC/DC Converter	-	13	
	Solar Panels & Substrate	8	20	
	Total	$ 14K	$ 69K	$ 55K
Propulsion	Isolation Valves	$ 13	$ 29	
	He Tank	1	8	
	Bellows & Misc.	1	2	
	Total	$ 15K	$ 39K	$ 24K
Total Equipment Savings including GFE				$371K

Conclusion:

Equipment reuse contributed total savings of 24% to SESP program cost. However, a portion of these savings was due to reuse of equipment as GFE items. The equipment reuse practice should be applied when commonality of hardware and inventory of such equipment exists. On the average, the SESP 71-2 program paid refurbishment costs of 30% or less on the equipment requiring refurbishment.

11.3.2 Low-Cost Practice: Minimum Spares

Impact: SESP 71-2 Recurring Cost Savings Estimate of $403K.

Description:

Minimum spares procurement and make costs consisted primarily of the costs of one tape recorder, some batteries, and parts only for critical black boxes. For other critical equipment items, arrangements were made with on-going A.F. programs to obtain spare items on short notice if they were required at the launch base.

SPARES BREAKDOWN:

Subsystem	Equipment	Cost to SESP	Est. Nominal Cost	Savings
S&C	Horizon Sensor	-	$ 30.0K	
	Gyro	-	6.5	
	Pro-Rated Spares Maint.*	10.0	5.8	
	Total	$ 10.0K	$ 42.3K	$ 32.3
TT&C	Tape Recorder	$122.7	$122.7	
	PCM-5	1.6 (Parts)	135.6	
	EIU		55.8	
	PCM-3		23.4	
	Pro-Rated Spares Maint.*	10.0	51.9	
	Total	$134.3K	$389.4K	$255.1
Electrical	Fuse Resistor J-Box	6.4(Parts)	8.0	
	Change Controller		33.0	
	Power Cont. Logic Assy.		33.0	
	Shunt Regulator		14.0	
	ONR Control J-Box		13.0	
	Battery Type 30 (1)		9.5	
	Battery Type 7 (3)	27.9	27.9	
	Pro-Rated Spares Maint.*	10.0	22.0	
	Total	$ 44.3K	$160.4K	$116.1K
Total Spares Costs & Savings		$188.6K**	$592.1K	$403.5K
Spares % of Flight Unit Cost:		3.2%	10.1%	6.9%

NOTES:

* Spares Maintenance and Repair costs on SESP 71-2 represent 15.9% of the spares hardware. Thus as spares hardware goes up these maintenance costs go up. These costs were pro-rated to subsystems.

**This cost represents the spares for the flight vehicle excluding $7.5K of GSE spares.

Conclusion:

The minimum sparing practice on SESP 71-2 (3.2% of unit cost) saved about 3% of the program cost as compared to the nominal sparing practices represented by 10 - 20% of flight unit or complete spare vehicles. In the case of SESP 71-2 this minimum sparing was possible due to hardware commonality and common equipment inventory with other programs. For example, the Type 30 battery spare was a non-flight item as declared by another program due to critical out of tolerance dimension. This condition was not critical to SESP and electrically the battery met all specifications.

11.3.3 Low Cost Practice: Refurbishment and Upgrading of Test Hardware to Flight Status

Impact: SESP 71-2 Unit Cost Savings of $110K

Description:

This practice consists of reusing the developmental and qualification test hardware, after refurbishment and upgrading, as flight hardware. On the SESP 71-2 the major occurrences of this practice involved the refurbishment of the heat exchanger qualification unit into a flight unit at estimated savings of $90K, and reuse of major structural elements such as forgings at savings of $20K. The latter were obtained as GFE items by disassembling a DTV (Developmental Test Vehicle) from another Agena program.

Conclusion:

This practice contributed minor savings (less than 1%) to the SESP 71-2 program cost, since this program had very little test hardware to begin with. However, on programs with considerable test hardware, the conversion of DTV's and qualification units into flight hardware may save considerably more and be a significant low-cost practice. The refurbishment of the $90K heat exchanger qualification unit to bring it up to flight status cost $14K or 16% refurbishment rate.

11.3.4 Low-Cost Practice: Quantity Buy of Equipment

Impact: Variable Savings Depending on the Cost of the Items and No. of Items Involved

Description:

Quantity-buy savings on common equipment items for several programs may be substantial. This practice is implemented as much as possible by contractors' central procurement organizations, which order a given equipment item in quantity to meet the requirements of several programs. As an extension of this practice, LMSC has procured items in quantity for "common equipment inventory" under a specific contract provision from the A.F. This equipment inventory would then be available to the using programs at lower costs than the costs the individual program would have to incur if it procured to satisfy only its own requirements. In some cases the common inventory equipment was treated as GFE material.

In the case of SESP 71-2, a single flight vehicle, the significant quantity-buy practice involved the Bell engine. It was ordered in a 14 engine lot at an average price of $359K. (The price for a single engine buy would have been considerably higher.) However, due to schedule pressures, the SESP program required an engine earlier than the scheduled delivery date and was able to substitute an engine from another program at the previous procurement

price of $330K. This resulted in additional savings of $29K plus a further $3K savings due to the fact that the substitute engine had already been screened (engine reliability verification) by the other program.

Other SESP 71-2 items benefiting from quantity procurement were batteries, switches, and many other parts for which it is difficult to extract the amount of cost savings involved.

Conclusion:

Only small savings could be identified and attributed to the practice of quantity buying on the SESP 71-2 program, but as a cost-saving practice it should be implemented whenever conditions permit.

11.3.5 High Cost Practice: Extensive System Test

Impact: SESP 71-2 Unit Cost Dissavings of ≈ $460K

Description:

The system test budget was overrun due to the following extensive testing: 1) integrated system test utilizing experiment simulators, 2) integrated system test repeated with installed experiments, 3) final system test with all specifications and requirements imposed, and 4) final systems test completed at VAFB.

The delays and repeated testing were due to late GFE experiments, non-availability of the remote site for testing of one experiment, and problems with the overall vehicle schedule slip of three weeks which caused scheduling problems at the system test complex.

Associated with higher test hours were the hour increases in data processing/analysis, documentation, and test management, as well as engineering and Q.A. support.

Conclusion:

These test dissavings represent about 2% of the program cost and can be eliminated by improved planning and scheduling. If the associated support cost impact is considered, the total dissavings approximate 3% of program cost with an additional estimated $220K expended in systems engineering, Q.A., management, and documentation activities.

11.3.6 High Cost Practice: In-House Make of PCM-5/EIU

Impact: SESP 71-2 Unit Cost Dissavings of ≈ $200K

Description:

The decision to make in house the new Pulse Code Modulation Unit Type 5 (PCM-5) and the associated Experiment Interface Unit (EIU) resulted in cost increase of ≈ $200K over the subcontractor's proposal. Contributing to this overrun were the PCM-5 crystal oscillator failure, which required requalification and associated support activity. It is impossible to say whether the subcontractor would have had the same overrun.

Conclusion:

More careful evaluation of in-house make vs. subcontracting, and the type of contract arrangement with the subcontractor might have reduced this negative cost impact of about 1% of SESP 71-2 program cost.

11.4 SESP 71-2 PROGRAM PRACTICES SUMMARY

The absolute estimated dollar savings and increases of SESP 71-2 practices were converted to percentages of program cost to provide a more generalized view of the low and high-cost practices impact on the program.

In order to permit percentage computations a hypothetical program cost had to be derived, omitting the inheritance impact. Fig. 4-1 shows this derivation and the contributions of the various practices to the program. The

		% OF HYPOTHETICAL PROGRAM COST
SESP 71-2 ACTUAL PROGRAM COST	$12.026M	78.7%
LESS HIGH-COST PRACTICES:		
o NR PRACTICES	- 0.329	- 2.2%
o EXTENSIVE SYSTEM TEST & SUPPORT	- 0.460	- 3.0
o IN-HOUSE MAKE VS. BUY	- 0.200	- 1.3
PLUS LOW-COST PRACTICES:		
o DESIGN & TEST	+ 0.720	+ 4.7
o DOCUMENTATION	+ 0.610	+ 4.0
o PROGRAMMATIC/MANAGEMENT	+ 2.000	+13.1
o EXISTING EQUIPMENT REUSE	+ 0.370	+ 2.4
o MINIMUM SPARES	+ 0.400	+ 2.6
o OTHER UNIT COST PRACTICES	+ 0.140	+ 0.9
SESP 71-2 HYPOTHETICAL PROGRAM COST	$15.277M	100.0%
NET LOW COST PROGRAM PRACTICES SAVINGS	$ 3.251M	21.3%

(INHERITANCE SAVINGS OF $30 - $46M NOT CONSIDERED)

Fig. 4-1 Program Practices Cost Impact

total net savings due to SESP 71-2 low-cost program practices were estimated at more than 20% of the hypothetical program cost. In other words, the actual SESP 71-2 cost represented 79% of the cost which could have been incurred if the low-cost practices were not implemented.

The practice of inheritance was not considered pertinent in this evaluation, because it may have been the major driver which permitted the SESP 71-2 to become a program in the first place.

ENGINEERING MEMORANDUM

LCPP-12

TITLE: Program Effects Relationships (PER) Survey	EM NO: LCPP-12 REF: DATE: 4-21-72
AUTHORS: D. L. Hannaford	APPROVAL: ENGINEERING SYSTEM ENGRG D. L. Hannaford

Section

PROGRAM EFFECTS RELATIONSHIPS (PER) SURVEY

12.1 Background

Program Effects Relationships (PER's) are line graphs, bar charts, data tables, etc. which identify the key parameters of alternative practices, management and technical, within a general program practice area and relate costs for accomplishing each alternative practice. For example, there are several well defined levels of Quality Assurance (Commercial, JANTX (general military), Hi-Rel military and Super Hi-Rel Lockheed/military). Each has separate sets of requirements and conditions to be met which in turn result in costs which range from one for commercial QA programs to eight times as much for Super Hi-Rel QA programs. Costs of individual components which do exactly the same job in a system but which are qualified to the requirements for different QA levels can range from one for the commercial level to 16 or 18 times that amount when qualified in accordance with Super Hi-Rel requirements. In concept PERs differ greatly from Cost Estimating Relationships (CERs). CERs, relate the cost of hardware/software elements to physical parameters of these elements. Use of historical CER's to predict cost of future programs assumes that future elements of hardware/software will always be developed in the same way and in accordance the same practices as were used in historical programs. Dependence on the use of such traditional CERs for estimating cost of future programs tends to preclude the use of new innovative management and technical practices which

could become low-cost drivers in future programs. In addition, when costs predicted via the traditional CER route are adjusted for inflation/escalation the resulting cost predictions tend to go only one way, up. On the other hand, the PER concept is dedicated to the proposition that new alternative practices can be devised which, in turn, will allow NASA to buy more spare operations for each NASA dollar. This concept recognizes the fact that no single set of practices can always be the most cost effect set for all future programs, and requires PERs to be developed to show the relative costs for implementing any of the several alternative practices considered practical within a particular practice area. Thus, if and when meaningful PERs can be developed to cover most program practice areas they can become powerful tools to assist cost-effective decision making in future programs.

During a previous study LMSC developed an initial set of PERs and a preliminary PER Handbook based on data from historical space program records. NASA/LMSC considered this handbook to be a good start toward development of a highly desirable program planning tool. However, several ifs were also recognized in the previous study effort. These ifs included but were not limited to; the availability of historical programatic and cost data to develop PERs covering the full range of program practices, PER content and format preferred by potential users and the probability of wide-spread acceptance/use of such a tool. Thus, a PER Survey was planned to be accomplished during the present study (before more PERs were generated) to obtain potential user inputs relative the recognized ifs.

While planning the PER Survey and developing a mutually agreed upon questionnaire NASA/LMSC decided to offer anonymity to prospective participants

for the following reasons:

a. NASA's major role has changed from that of transforming science fiction type space concepts into real-world space operations for the first time to that of providing more economical space operations based on experience gained via 17 years of successful operations and the expenditure of more than fifty billion dollars.

b. In view of present economic conditions NASA has a more urgent need to acquire more space for each NASA dollar than it has had in all its previous existence.

c. Candid recognition, isolation and quantification of historical high-cost diriving practices are essential steps in developing meaningful PERs

d. The act of identifying and quantifying historical high-cost driving practices would place prospective participants in the awkward position of having to be critical (from the economic point of view) of some NASA practices that were used to make space flight a reality in the first place

e. Involved people within the NASA and industry are sensitive to making/accepting statements which tend in any way to be critical of past accomplishments and/or practices.

During the survey 33% of the participants elected this option, 49% did not and 18% did not state a preference.

12.2 Per Survey Objectives

General objectives were to obtain and incorporate USER INPUTS from a representative cross section of potential NASA/Industry users into NASA's

PER Handbook development efforts and to promote open dialog relative to developing low-cost space programs in the near future. Detailed objectives included:

a. Specific Practice Areas for which PER's are needed.

b. Scope of Coverage needed for best user application.

c. Practical Range of high-to-low cost practices to cover in each PER set pertaining to program practice areas such as:

- o Program Management
- o General Contracting
- o Specifications
- o SE&I
- o GSE
- o QA & Reliability

d. Preferred PER and PER Handbook Format(s)

e. Potential usefulness evaluation

f. Status and availability of historical data for generating a full set of PERs.

g. "How-Best-To" comments:

- o Promote implementation of low cost spacecraft programs in near future.
- o Apply and use PER Handbook effectively.

12.3 Scope of Survey

The scope of effort planned and accomplished is outlined below.

INTERVIEWS

- o Ten NASA Field Center project/spacecraft managers.
- o Ten NASA Field Center functional division managers.
- o Three NASA/HQ program managers (OSS, QA, OMSF).
- o Nine Industry program/functional division managers representing at least five companies.

DOCUMENT INTERVIEW RESULTS

- Answers to questionnaires.
- Interview comments (Pro and Con).
- Related activity/interface ideas and comments.
- Unanticipated inputs/constraints.
- Special data for new PER's (Specs, SE&I, GSE)

PERFORM COMPOSITE ANALYSIS OF INTERVIEW RESULTS

- Summarize requirements; preferences; limitations.
- Generate "preferred" content/format(s) for PER's and PER Handbook.
- Document rationale for "preferred" PER approaches.

12.4 Participants

Due to the anonymity option elected by 33 percent of survey participants individual names are not listed. The names of participating organizations and numbers of questionnaires completed by each are:

NASA	
Ames	5
GSFC	6
JSC	9
MSFC	7
NASA HQ	2
Total	29

INDUSTRY	
Hughes	2*
JPL	6
LMSC	2
Martin	3
Philco	3
SCD	1**
TRW	3
Total	20

* Selected teams of personnel completed two questionnaires.

** Only one requested from Systems Development Corporation.

Several other NASA and industry organization initially contacted were willing to participate but were not needed to satisfy the scope of effort planned and, reluctantly, were not included due to time and money constraints.

12.5 Survey Implementation

Essential steps used to implement this survey were:

a. Prepared and obtained NASA approval of a basic survey Implementation Plan, Orientation Brochure and Survey Questionnaire.

b. Mailed orientation brochures and questionnaires to participants prior to conducting face-to-face orientation briefings and interviews.

c. Provided participants the choice of completing questionnaires during interviews or to use the interview periods for expanded discussions and to mail in completed questionnaires later.

d. Maintained follow-up contact via telephone to answer additional questions and to receive modified/updated inputs.

f. At the request of several participants, supplemental agreements were made during meetings/interviews which allowed participants to:

- Omit responses to questions he felt unqualified to answer
- Alter the wording of questions where he felt it would help clarify the full meaning of his response
- Add additional questions and answers if he felt any significant questions were omitted.

12.6 Survey Results

Results are presented in five separate parts. These are:

- Compiled on a questionnaire form
- Summary of key responses
- Additional comments from oral discussions
- Conclusions
- Recommendations

12.6.1 Results Compiled on Questionnaire

To the extent practical all relevant questionnaire response are displayed/ quantified on a copy of the questionnaire form used in the survey. This

"long-form" format is used to provide the reader the best possible feel for the full significance of responses obtained including why some resulting answers tend to be critical of a few historical practices (NASA's, DOD's and Industry's) from the cost point of view. It was also used to provide the reader an opportunity to compare his feelings, beliefs and convictions with those obtained in this survey.

Quantifible results have been quantified to reflect the total number of NASA and industry responses to each question separately and combined. No attempt was made to quantify differences in response trends between program managers and functional managers nor between organizational levels of individual participants. Such breakdowns were considered meaningless due to the facts that some program managers are ex-functional managers (visa versa) and there is no common denominator for comparing responses from individuals in organizational levels ranging from first-line managers to Directors in the NASA and the president of one industrial company.

A total of 49 participants completed or supervised teams to complete questionnaires to the extent they deemed practical. Of these, 15 are program/project managers, 33 are functional managers, 1 is president of an industrial company, 29 are NASA personnel and 20 are industry personnel.

An example of how individual responses are recorded is as follows. Under the questionnaire section covering SCOPE OF PER COVERAGE several practice areas such as SPECIFICATIONS, DOCUMENTATION, etc. are listed. Participants were asked to indicate their judgment of the cost impact of the practices used in each practice area on the total cost of space programs as H-high, M-

moderate or L-low. Three rows of numbers are used to record cost impact responses. The top row of numbers reflect NASA responses under H, M, L and T^1 for the total number of NASA answers received. The second row reflects industry response under the same cost impact headings. The third row shows the totals of the first two rows when added as columns under H, M, L and T^1. Thus, the cost impact responses recorded under SPECIFICATIONS are

	H	M	L	T^1
NASA	20	5	2	27
Industry	14	5	1	20
Total	34	10	3	47

Participants were also asked to indicate a priority of preference for PER's covering each practice area. The same arrangement of rows and columns is used to record NASA and industry responses separately and combined for each practice area. Priorities are ranked from 1 to 5 with 1 indicating the highest priority. Columns 5 includes priorities 5 and above as very few indicated beyond the fifth level.

Participants were also asked to indicate which of several sub-topics they believed to be important within each practice area. In these cases, only one row of numbers is used to indicate all responses. The first and second numbers indicate NASA and industry responses respectively and the third reflects the total of the two. This number arrangement is used in all remaining cases where a single row of numbers could be used to adequately reflect the quantities of responses received. Elite type has been used to identified "write-in" type responses.

QUESTIONNAIRE

PROGRAM EFFECT RELATIONSHIPS (PER'S)

Question Topics Covered

1. Scope of PER Coverage
2. Content/Format of PER's and Handbook
3. Usage of PER's and Handbook
4. Method of Generating/Validating PER Handbook
5. Low-Cost Practice Implementation Considerations
6. Availability of Data for Current/Future PER's
7. Opinions on Current/Future Program Practices

Special Notes:

(1) Answers to this questionnaire are being acquired and assembled for the NASA/HQ, Low Cost Systems Office, by Lockheed Missiles & Space Company as part of a current study contract on Low-Cost Program Practices.

(2) This questionnaire package is being sent to allow time for preparation prior to the planned personal interviews. For orientation and background relating to the questionnaire, two supplementing documents are being supplied:

(a) LMSC-D387543 dated 4 October 1974, "Program Effect Relationships (PER's) - Survey Orientation

(b) LMSC-D387518 dated 30 May 1974, "PER Handbook - Appendix 1, Final Report on Low-Cost Program Practices"

(3) It is the intent of the survey that all answers be as candid and objective as is feasible. Therefore, if it is desired by the interviewee that his responses be treated in an anonymous manner in any published summary report on the survey, this will be done.

(4) This PER survey and analysis of results will provide NASA/HQ with sufficient data upon which to base further action on PER development and NASA Center/Industry participation.

PER SURVEY QUESTIONNAIRE

Person Answering: Date of Answer: ____________

Name: ____________ Title: ____________

NASA Center or Company: ____________ Division: ____________

Orgn. Name: ____________ No: ________ Phone: ________

Mailing Address: ____________

Anonymity Requested: ☐ Yes 8 + 8 = 16 ☐ No 15 + 9 = 24

LMSC Contacts:

(a) Please direct all inquiries or special information by telephone to LMSC:

Dale Hannaford	Orgn. 61-50	(408) 742-8207
Keith Burbridge		(408) 743-1439
Wayne Miller		(408) 743-1845

(b) For information that must be mailed, please address to:

Wayne Miller, Advanced Payload Systems
Lockheed Missiles & Space Company, Inc.
Space Systems Division
Orgn. 61-50, Bldg. 104
P. O. Box 504
Sunnyvale, California 94088

1. SCOPE OF PER COVERAGE

1.1 What principal Program Practice areas and subtopics should be emphasized in new PER development?

(1) Mark high "H", moderate "M", or low "L" for estimate of cost impact of practice on spacecraft programs.

(2) Mark numbers 1, 2, 3, etc., for priority of preference for PER's covering the practice areas.

(3) Mark an "X" in the subtopic block(s) which is/are believed most important.

Cost Impact H	M	L	T	Practice Area	Priority I	II	III	IV	V
				SPECIFICATIONS					
20 +	5 +	2 =	27	☐ Qty. Growth 3+9=12 ☐ Project Peculiar 9+8=17	11	4	5	1	4
14 +	5 +	1 =	20	☐ Redundancy, Interrelations 10+16=26	13	4	1	0	0
34	10	3	47	☐ Level-Applied (Commercial, MIL, etc.) 19+9=28	24	8	6	1	4
				☐ WORK IMPOSED 3+2=5					
				DOCUMENTATION					
6	20	3	29	☐ Qty., Redundancy, Revisions 22+16=38	5	3	3	4	9
5	13	2	20	☐ Type, Degree 16+6=22 ☐ Format 2+6=8	7	6	4	0	0
11	33	5	49	☐ Control and Classification 7+7=14	12	9	7	4	9
				☐ Preparation vs Reading 7+4=11					
				☐ SCOPE OF COVERAGE 1+3=4					
				CONTRACTING PRACTICES					
5	11	11	27	☐ Procurement Procedures 13+12=25	3	7	2	2	9
11	6	3	20	☐ ASPR Influence 2+5=7 ☐ RFP/Proposal 11+10=21	5	4	6	0	0
16	17	14	47	☐ Extensive Boiler Plate 7+5=12 ☐ Contract Negotiation 8+6=14	8	11	8	2	9
				☐ Impact on Contractor Overhead 8+7=15					
				☐ QUANTITY OF INTERFACES 0+3 =3					

Cost Impact H	M	L	T	Practice Area	Priority I	II	III	IV	V
26	0	3	29	PROGRAM DEFINITION	13	6	4	1	2
15	4	1	20		13	3	2	1	0
41	4	4	49		26	9	6	2	2
7	13	6	26	SYS. ENGR. & INTEGRATION (SE&I)	3	5	4	0	11
4	9	4	17		3	4	6	0	1
11	22	10	43		6	9	10	0	12
12	13	3	28	NASA PROGRAM MANAGEMENT	9	4	2	2	7
14	2	1	17		10	4	1	0	0
26	15	4	45		19	8	3	2	7
10	13	5	28	R/QA	5	3	4	3	7
9	8	3	20		8	4	2	2	0
19	21	8	48		13	7	6	5	7

PROGRAM DEFINITION

- ☐ Changes 26+15=41
- ☐ New Technology Development 8+6=14
- ☐ Phased Project Planning 10+6=16
- ☐ Scheduling 8+8=16
- ☐ Contingency Allowances 9+9=18
- ☐ Inflation Allowance 6+7=13
- ☐ WHEN FINALIZED? 1+1=2

SYS. ENGR. & INTEGRATION (SE&I)

- ☐ Value of Functions 12+6=18
- ☐ COST/WORTH EVALUATION 3+1=4

NASA PROGRAM MANAGEMENT

- ☐ Mgmt. Risk 16+5=21
- ☐ Mgmt. Planning 11+2=13
- ☐ Mgmt. Procedures/Controls (C-Spec, WBS) 13+6=19
- ☐ Contractor Interfaces 9+10=19
- ☐ NASA/Contractor Personnel Functions/Ratios 9+12=21
- ☐ Review/Approval Cycles 16+8=24
- ☐ ________

R/QA

- ☐ Level of Reliability Analysis/Test 17+11=28
- ☐ Degree of QA, Inspection 10+10=20
- ☐ NASA/Contractor QA Redundancy 7+12=19
- ☐ Hardware Risk Acceptance 15+8=23
- ☐ Redundant Supplier Audits 4+6=10
- ☐ Value of R/QA Functions 11+6=17
- ☐ REVIEW BOARD CYCLE TIME 1+1=2

Cost Impact H	M	L	T	Practice Area	Priority I	II	III	IV	V
				GROUND SUPPORT EQUIPMENT (GSE)					
4	17	7	28	☐ Level of Requirements (Commercial, MIL, Flight) 19+10=29	2	2	6	2	11
5	11	4	20	☐ Qty. vs Location vs Scheduled Usage 12+9=21	3	12	3	1	0
9	28	11	48	☐ Commonality 13+7=20 ☐ Inventory and Reuse 10+7=17	5	14	9	3	11
				☐ STE, AGE, FSE 3+3=6					
				☐ ____					
				TESTING					
10	16	3	29	☐ Component vs Subsystem vs System 20+9=29	4	4	6	4	6
12	6	2	20	☐ Redundant Testing 10+8=18	8	6	3	1	0
22	22	5	49	☐ Test Cost vs Program Success 15+8=23	12	10	9	5	6
				☐ NASA vs Contractor Testing 4+4=8					
				☐ OVER THE SHOULDER SURVEILLANCE 1+2=3					
				ENGINEERING					
12	13	3	28	☐ Value of Functions (degree of analysis) 15+6=21	7	2	1	4	7
2	8	4	14	☐ Reporting Formality & Quantity 1+2=3	3	3	3	1	3
14	21	7	42		10	5	4	5	10
				MANUFACTURING					
7	11	6	24	☐ Processing 6+4=10 ☐ Tooling 4+4=8 ☐ Mfg. Test 3+7=10	3	2	2	0	1
6	6	3	15	☐ Mfg. Planning 11+8=19 ☐ Subcontracting 9+4=13	4	2	2	0	2
13	17	9	39	☐ Material Procurement 8+5=13	7	4	4	0	3
				☐ ____					
				MAINTENANCE AND LOGISTICS					
2	12	12	26	☐ Type/Degree $\overline{M}$ 9+3=12	1	3	6	1	12
1	8	11	20	☐ Spares Qty./Program vs Multi-Program Usage 14+11=25	2	7	4	2	1
3	20	23	46	☐ Field Repair/Refurbishment vs Discard 5+3=8	3	10	10	3	13
				☐ ____					
				(Other) ____					
				(Other) ____					

1.2 Cost information (vs program practice) on PER should be at what level(s)?

a) ☐ Program 16+10=26   b) ☐ Spacecraft 11+10=21   c) ☐ Subsystem 21+10=31

d) ☐ Component 4+3=7   e) ☐ FUNCTIONAL TASKS 1+5=6

1.3 Cost information on PER should be in terms of what echelon of cost accumulation?

a) ☐ Contractor costs only. 4+3=7

b) ☐ NASA, Contractor separately. 17+11=28

c) ☐ NASA plus Contractor combined. 7+6=13

d) ☐ ______________________

1.4 The practical range of cost vs practice on a PER should cover what classes of hardware?

a) ☐ Commercial 9+4=13   b) ☐ Commercial Aircraft 13+11=34

c) ☐ Military Aircraft 14+3=17   d) ☐ Spacecraft 26+20=46

e) ☐ ALL 2+3=5

1.5 Should PER's be limited to cover unmanned spacecraft only or extended to cover other hardware?

a) ☐ Experiments or Mission Equipment 18+12=30

b) ☐ Manned Spacecraft 18+8=26   c) ☐ Space Shuttle 16+8=24

d) ☐ LIMIT TO UNMANNED SPACE PROGRAMS 1+2=3

2. CONTENT/FORMAT OF PER'S AND HANDBOOK

2.1 Should PER data be limited to historical data accumulation or show estimated data for lower cost practices?

a) ☐ Historical data only (like CER's). 2+4=6

b) ☐ Historical data plus comparative estimates of using lower cost approach. 19+18=37

c) ☐ Estimates for lower cost approach only. 1+1=2

d) ☐ (b) PLUS CHANGING ECONOMIC FACTORS 1+2=3

2.2 Which data sources should be included in PER or User Instructions?

a) ☐ Historical data. 14+10=24

b) ☐ Rationale and/or derivation of low-cost practice estimate. 22+17=39

c) ☐ ______

2.3 Types of historical data to be included in data sources or backup data?

a) ☐ Specific programs 21+13=34

b) ☐ Specific document(s) 6+3=9

c) ☐ Specific contract 12+8=20

d) ☐ ALL 1+0=1

2.4 What is preference for individual PER format?

a) ☐ Line Graph 20+15=35

b) ☐ Table 10+8=18

c) ☐ Bar Chart 9+5=14

d) ☐ Mathematical Equation 3+3=6

e) ☐ Mathematical Equation

f) ☐ ALL 3+4=7

2.5 User Instructions for PER's?

a) ☐ Separate sheet with each PER. 10+8=18

b) ☐ On face of PER. 9+7=16

c) ☐ All combined in one section of Handbook. 5+6=11

d) ☐ AS REQUIRED FOR BEST USE 1+1=2

2.6 For each of the major PER practice areas listed in Question No. 1.1, what specific parameters displayed on PER would appear to be of greatest value in your planning and estimating? For example, under "Specifications":

- o Degree of Safety Certification vs Relative Cost
- o Maintenance Index vs Relative Cost

a) Specification Parameters

(1)	NEED FOR EACH SPEC PARAMETER.	vs	GOVERNMENT & INDUSTRY COST FOR PREPARATION OF & FOR MEETING EACH PARAMETER
(2)	OVERALL COST OF NASA CURRENT SPEC APPROACH.	vs	ALTERNATIVE LOW COST APPROACHES.

b) Documentation Parameters

(1)	QUANTITY OF	vs	MANAGEMENT EFFICIENCY
(2)	MULTIPLE DRAWING CHECKS	vs	COST OF EACH CHECK BY FUNCTIONAL ORGANIZATION VS. WORTH EVALUATIONS.

c) Contracting Practice Parameters

(1)	TYPE OF CONTRACT	vs	GOVERNMENT & INDUSTRY ADMIN. COSTS
(2)	TYPE OF CONTRACT	vs	OVER/UNDER RUNS BASED ON Ø C/D NEGOTIATED COSTS.
(3)	LEVEL & FREQUENCY OF GOVERNMENT AUDIT/REVIEWS		COST OF SAME VS PROGRAM OVER/UNDER RUNS.

d) Program Definition Parameters

(1)	DEGREE COMPLETE FOR EACH PHASE.	vs	NO. & COST OF CHANGES IN Ø C/D
(2)	COST OF COMPLETELY DEFINING ALL TECH. & MGMT. ASPECTS OF PROGRAM DURING Ø B.	vs	COST OF SURPRISES, CHANGES, REDESIGN & REMANUFACTURE WHEN PD IS FINALIZED IN Ø D.

e) SE&I Parameters

(1)	OVERLAP & REDUNDENCY WITH OTHER GROUPS	vs	COSTS OF OVERLAP
(2)	COST OF SE&I	vs	TOTAL PROGRAM COSTS WHEN FORMAL SE&I IS USED & IS NOT USED.

f) NASA Program Management Parameters

(1)	MAJOR POLICIES AND PROCEDURES.	vs	REAL & IMAGINARY COST IMPACTS ON PROGRAMS
(2)	TECHNIQUES	vs	COST OF EXISTING TECHNIQUES AND ALTERNATIVE TECHNIQUES

g) R/QA Parameters

(1)	COST OF EXISTING PRACTICES.	vs	PROGRAM COST & SUCCESS.
(2)	RANGE OF R&QA COSTS FOR HISTORICAL PROGRAMS	vs	DEGREE OF SUCCESS ACHIEVED IN EACH PROGRAM.

h) GSE Parameters

(1)	DEGREE OF DEFINITION & COST EST. AT END OF EACH PHASE.	vs	COMPLETED PROGRAM DEFINITION & COSTS.
(2)	STD COMPONENTS (MAXIMUM)	vs	PROGRAM COSTS WITH & WITHOUT STANDARDIZATION.

i) Testing Parameters

(1)	LEVEL & AMT. OF TESTING.	vs	PROGRAM SUCCESS & COSTS.
(2)	REDUNDANT TESTING.	vs	REDUNDANT COSTS IMPOSED (MANHOURS, EQUIP., FACILITIES, TRANSPORT.)

j) Engineering Parameters

(1)	NO. OF ENGINEERING DISCIPLINES & ORGANIZATIONS.	vs	COST OF EACH & INTERFACE COSTS.
(2)	COST OF MEETING PRESENT REQUIREMENTS.	vs	COST OF MEETING MINIMUM REQUIREMENTS TO COMPLETE MISSION.

k) Manufacturing Parameters

(1)	COST OF MFG. PLANNING MANAGING & CONTROL	vs	COST OF ACTUAL FAB, ASSY, & TEST EFFORTS.
(2)	EXTRA COST DUE TO GOVERNMENT HOW TO SPECS.	vs	COSTS OF USING CONTRACTOR HOW-TO PROCEDURES WITHOUT GOVERNMENT SPECS.

l) Maintenance and Logistics Parameters

(1)	SPECIAL REQUIREMENTS BY EACH CUSTOMER.	vs	EXISTING CONTRACTOR PRACTICES.
(2)	COSTS DUE TO PRESENT SPEC REQUIREMENTS.	vs	ALTERNATIVE LOW-COST PRACTICES.

m) (Other) CONTRACT MONITORING Parameter

(1)	COST OF USING OF PREPLANNED MONITORING QUESTIONNAIRES & QTRLY. PERSONNEL CONTACTS, WKLY. PHONE CALLS BETWEEN A FEW RESPONSIBLE INDIVIDUALS.	VS	MONITORING BY THE "BIG TEAM" MEETINGS & EXCESSIVE FORMAL DOCUMENTATION NOW BEING USED.

n) (Other) MEETINGS RECORD FORMS Parameter

(1)	RECORD ALL NASA & INDUSTRY COSTS ASSOCIATED WITH EACH MEETING & REVIEW & SHOW WHAT DECISIONS ARE MADE, IMPLEMENTED, CHANGED OR POSTPONED AND GIVE REASONS WHY.	VS	

2.7 In what form should the relative cost of alternate practices be provided on a PER?

- ☐ % of Total Program Cost 11+6=17
- ☐ Cost factors (multipliers) 9+6=15
- ☐ Delta cost among alternatives 17+12=29
- ☐ ______________________

3. USAGE OF PER'S AND HANDBOOK

3.1 Is there a preferred organizational level or personnel to which primary usage of PER's be directed?

a) ☐ Planners 8+3=11 b) ☐ Program Managers 23+14=37

c) ☐ Estimators 10+7=17 d) ☐ Senior Management 13+4=17

e) ☐ Functional Organization: 10+12=22

☐ Contracts 5+7=12 ☐ Finance 2+7=9

☐ Manufacturing 5+7=12 ☐ R/QA 7+7=14

☐ Procurement 9+6=15 ☐ Engineering 10+10=20

☐ Testing 5+3=8 ☐ Operations 3+5=8

☐ ________ ☐ ________

f) ☐ (Other) ________

3.2 What is primary use(s) contemplated for PER's?

a) ☐ Supplementing other estimates. 7+6=13

b) ☐ Evaluating estimates made with CER's, bottom-up or other means. 5+4=9

c) ☐ Basis for primary program decisions. 17+6=23

d) ☐ For general cost tradeoffs. 18+9=27

e) ☐ AVOIDING UNNECESSARY COSTS 1+3=4

3.3 Could PER's developed primarily for NASA usage be also of value for use by Industry?

a) ☐ Most 8+6=14 b) ☐ Some 15+11=26 c) ☐ None 2+0=2 d) ☐ ________

3.4 What organizations in your facility would use PER's if they were available?

a) ☐ Top Management 7+4=11   b) ☐ Program Managers 18+11=29

c) ☐ Functional Organizations (list) 14+9=23

ENGINEERING 3+5=8   MANUFACTURING 0+3=3

R&QA 2+2=4   ESTIMATING 0+3=3

TEST & DPS 1+2=3

d) ☐

e) ☐

3.5 List potential limitations or reservations for usage of PER's or Handbook at your facility.

☐ LACK OF ACCURATE/ADEQUATE HISTORICAL DATA

DATA CREDIBILITY

☐ PEOPLE DON'T READ NOR USE EXISTING HANDBOOKS

☐ RELUCTANCE TO CHANGE SAFE & COMFORTABLE PRACTICES EVEN IF THEY ARE HIGH COST

4. METHOD OF GENERATING/VALIDATING PER HANDBOOK

4.1 Is a NASA-wide PER Handbook considered feasible and desirable?

a) ☐ Yes 15+12=27 b) ☐ No 10+3=13

4.2 What basic method(s) recommended for NASA preparation, issuance, maintenance of PER's?

a) ☐ NASA/HQ prepare a general usage set of PER's. 11+7=18

b) ☐ Each NASA Center prepare selected groups of PER's, coordinated by NASA/HQ. 9+4=13

c) ☐ Each NASA Center prepare a separate PER Handbook for its own use. (Send copies to other Centers for information.) 6+3=9

d) ☐ DON'T DO IT 1+2=3

4.3 To what degree should Industry contribute to or participate in PER preparation?

a) ☐ Active 22+11=33 b) ☐ Advisory Only 6+7=13 c) ☐ None d) ☐ ______

4.4 Will PER's showing only relative cost factors (or % of total program cost) for alternate program practices be a significant planning tool even though they cannot be used to sum the total cost of a program element in absolute dollars or man-hours?

a) ☐ Yes 22+13=35 b) ☐ No 6+3=9

4.5 Is actual validation on a sample program(s) required before general usage of a PER or sets of PER's is implemented?

a) ☐ Yes 11+4=15 b) ☐ No 17+13=30

4.6 What type/level of validation is required before new low-cost practice PER's should be applied to new programs?

a) ☐ Actual proof on 1 to 5 (qty.) pilot program(s) with low-cost practices applied. 11+4=15

b) ☐ Verify logic and probability of significant saving with low-cost practices by theoretical calculations (cost tradeoffs) on specific program before application of PER's. 9+6=15

c) ☐ No prior validation; apply lowest cost practice which is judged to meet the mandatory-minimum program requirements (Program Manager decision). 8+9=17

d) ☐ (Other) WHY BE CONCERNED WITH VALIDATION NOW? EXISTING PRACTICES GREW WITHOUT FORMAL VALIDATION.

5. LOW-COST PRACTICE IMPLEMENTATION CONSIDERATIONS

5.1 Do you feel current laws and NASA regulations (ASPR, etc.) must be changed to allow implementation of low-cost practices?

a) ☐ Yes 7+11=18 b) ☐ No 13+4=17

☐ Which ones? ASPR

☐ What primary changes? CHANGE CONTRACTING APPROACHES AND REGULATIONS FROM THE PRE-WWII "HOUSEKEEPING" SUPPORT PHILOSOPHY REQUIRING SPACE PROGRAM CONTRACTS TO BE EXCEPTIONS TO INCLUDE 1970-1980 STYLE, STREAMLINE REQ'S. FOR ACQUIRING LOW-COST NO FRILLS SPACE PROGRAMS.

5.2 Do you believe PER's can be an effective method for aiding near-term transition to low-cost practices and lower-cost space programs? PROGRAMS.

a) ☐ Yes 18+13=31 b) ☐ No 6+4=10

5.3 Can you suggest a better basic method or "tool" for achieving lower space program costs?

☐ CHANGE TOP LEVEL POLICIES & PROCEDURES TO DEMONSTRATE LOW-COST LEADERSHIP.

☐

5.4 What principal areas of program practices appear to have the highest probability of actual change to low-cost approaches, and in what order?

☐ STANDARDIZED SPACE HARDWARE

☐ REDUCTIONS IN TESTING, R&QA, SPECS & DOCUMENTATION

☐ IMPROVED PROGRAM DEFINITION

☐ DEDICATION OF HIGH LEVEL LEADERSHIP TO LOW COST PRACTICES IN FUTURE PROGRAMS.

5.5 What organizational level of authority would be desirable or necessary for directing implementation of low-cost practices?

- [ ] NASA: TOP HQ MGMT & FIELD CENTER DIRECTORS
- [ ] Industry: TOP COMPANY MGMT.

5.6 For maximum impact on program cost reduction, should PER's or PER Handbook be applied as:

	NASA	Contractor
☐ Set of guidelines for program	☐ 21+13=34	☐ 18+9=27
☐ Firm operating requirements document	☐ 4+3=7	☐ 2+2=4
☐ Formal contract requirement	☐ 0+3=3	☐ 1+4=5
☐ ______	☐	☐

5.7 For maximum impact on program cost reduction, where within NASA and Industry should principal responsibility for implementing low-cost practices be assigned?

a) NASA

- [ ] Autonomous NASA Centers 6+7=13
- [ ] Centralized NASA Function (Lead Center) 2+1=3
- [ ] NASA/HQ 10+6=16
- [ ] Individual Program Offices 15+3=18
- [ ] ______

b) Industry

- [ ] Corporate Management 6+4=10
- [ ] Company Management 6+2=8
- [ ] Division Management 7+6=13
- [ ] Individual Program Offices 12+9=21
- [ ] Individual Functional Organizations 6+2=8
- [ ] ______

5.8 What controls/feedback/evaluation measures would you recommend to assess actual implementation and cost impact of low-cost practices during each phase of a program?

- ☐ NASA Central Monitoring 8+4=12
- ☐ Separate Program Monitors 11+4=15
- ☐ Informal Re-Surveys 6+9=15
- ☐ Written Progress Reports 3+0=3
- ☐ ______________________

6. AVAILABILITY OF DATA FOR CURRENT/FUTURE PER'S

6.1 What data pertinent to program practice area or sub-practice vs cost impact are now available for potential inclusion in PER sets or in Handbook?

Program Practice (vs Cost Impact)	Document or Source
1 533 FORMS & POP'S	☐
2 PMR'S	☐
3 CONTRACT FILES	☐
4 PERFORMANCE SPECIFIED VS. DEVELOPMENT COSTS.	☐ CONTRACT FILES
5 HISTORICAL DATA NORMALLY NOT RECORDED TO LEVEL OF DETAIL REQUIRED.	☐ NOT IN NASA FILES NOT IN CONTR FILES

6.2 In what status is "available" data?

- ☐ Dead storage (not readily retrievable). 2+3=5
- ☐ Readily retrievable from central files. 0+2=2
- ☐ Readily retrievable from program files. 6+1=7
- ☐ Hard copy available. 4+0=4
- ☐ LIKE PULLING HEN'S TEETH 1+4=5

6.3 Do you feel that the NASA historical programmatic and cost records in your Center or Company are adequate for generating meaningful PER's?

☐ Yes 5+4=9 ☐ No 20+8=28 ☐ 1+0=1 ADEQUATE FOR JUDGEMENT LEVEL ANALYSES, BUT NOT FOR QUANTITATIVE LEVEL.

6.4 Could data (6.1) be made available for general use by:

☐ NASA 13+5=18 ☐ Other Contractors 7+0=7

7. OPINIONS ON CURRENT/FUTURE PROGRAM PRACTICES

7.1 What percentage of program cost reduction could be obtained by implementing low-cost practices?

☐ 0% 1+0=1 ☐ 10% 6+2=8 ☐ 25% 10+11=21 ☐ 50% 6+3=9 ☐ 75% 0+0=0 ☐ 15-20% ____% 2+3=5

7.2 In what principal areas are NASA Centers and Industry actively trying to reduce costs?

☐ Eliminating desirable but non-mandatory tasks. 18+9=27

☐ Reducing requirements. 20+4=24

☐ Technical 16+2=18 ☐ Mgmt. 13+2=15 ☐ Reporting 15+2=0

☐ Testing 3+1=4 ☐ ____________

☐ Personnel utilization improvement 5+6=11

☐ Overhead functions/facilities 12+5=17

☐ Assuming larger risks 15+5=17

☐ STANDARDIZING HARDWARE 1+2=3

6.1.2. SUMMARY OF KEY RESPONSES

Listed hereunder are those responses to the Survey, which are believed to be representative prevailing opinions held by the interviewees. Of necessity, the answers listed have been generalized to allow simple categorization. Of particular interest is the predominating opinion that should Low Cost Practices be implemented, program cost reductions of the order of 25% TPC would be possible. This view was held by over 40% of the respondees.
For quantification purposes, the word "Other" is used to denote the percent of answers left blank and/or qualified to the extent that they were not deemed applicable responses to the question asked.

1. What percentage of program cost reduction could be obtained by implementing Low Cost Practices?

% Savings	% of 49 Responses
0	2
10	16
15-20	10
25	43
50	18
Other	11

The remainder of the responses to the 15 questions posed by the Survey have been summarized in a similar manner, and follow on Pages 31 thru 35.

The following questions, and their accompanying responses, should not be considered as in order of importance. The order is only that in which the questions were asked. No attempt has been made to weight the responses statistically:

2. Do you feel that the NASA historical programmatic and cost records in your Center or Company are adequate for generating meaningful PER's?

Yes	18%
No	57%
Other	25%

3. Should PER data be limited to historical data accumulation or show estimated data for lower cost practices?

Historical data only (like CERs)	12%
Historical data plus comparative estimates of using lower cost approach	76%
Estimates for lower cost approach only	4%
Other	8%

4. What is primary use(s) contemplated for PER's? *

Supplementing other estimates	27%
Evaluating estimates made with CER's, bottom-up or other means	18%
Basis for primary program decisions	47%
For general cost tradeoffs	55%
Other	8%

*This total of 147% indicates some participants contemplated multiple uses for PER's.

5. Could PER's developed primarily for NASA usage be also of value for use by Industry?

Yes	82%
No	4%
Other	14%

6. Do you believe PER's can be an effective method for aiding near-term transition to low-cost practices and lower-cost space programs?

Yes	63%
No	2%
Other	35%

7. Will PER's showing only relative cost factors (or % of total program cost) for alternate program practices be a significant planning tool even though they cannot be used to sum the total cost of a program element in absolute dollars or manhours?

Yes	71%
No	18%
Other	11%

8. Is a NASA-wide PER Handbook considered feasible and desirable?

Yes	55%
No	27%
Other	18%

9. What basic method(s) recommended for NASA preparation, issuance, maintenance of PER's?

NASA/HQ prepare a general usage set of PER's	37%
Each NASA Center prepare selected groups of PER's, coordinated by NASA/HQ	27%
Each NASA Center prepare a separate PER Handbook for its own use. (Send copies to other Centers for information.)	18%
Other	18%

10. What is preference for individual PER format?

Line graph	72%	Mathematical equations	12%
Table	37%	All forms OK	14%
Bar chart	29%		

11. User Instructions for PER's?

Separate sheet with each PER	37%
On face of PER	33%
All combined in one section of Handbook	22%
Other	8%

12. Which data sources should be included in PER or User Instructions?

Historical data	49%
Rationale and/or derivation of low-cost practice estimate	80%

13. Types of historical data to be included in data sources or backup data?

Specific programs	69%	Specific document(s)	18%
Specific contract	12%	All applicable	2%

14. To what degree should Industry contribute to or participate in PER preparation?

Active	67%
Advisory only	27%
Other	6%

15. Can you suggest a better basic method or "tool" for achieving lower space program costs?

Thirty-five percent suggested other general approaches, but these did not include specific "tools." Suggestions included:

a. Choose Project Managers based on past (low-cost as well as success) performance

b. Have top management dictate less-detailed management while continuing to mandate lower budgets

c. Make achieving low costs a challenge to Project Managers, not a set of detailed rules from upper management

d. Establish early, complete and firm program definition

e. Use only fixed-price contracts

f. Create a vehicle to continuously spread the low-cost word

g. PERs are only a start--all implications must be understood, including program and personal (career) risks

h. Use PERs or something similar in a mandatory educational program for key program management and administrative personnel

i. Use MIL-STD-499 in complementary role with PERs

j. Concentrate on cost-effects of top level policy

k. NASA managers need motivation, direction, and effective examples from top management relative to low-cost performance

l. Simply give a Program Manager a fixed dollar budget and make clear his job depends on not exceeding it

m. Convince everyone involved (NASA and Industry) that low costs are mandatory; then let managers and workers devise their own cost reduction approaches

n. Establish absolute cost ceiling on each and every major cost element of a program

   o Hold each functional manager (technical and administrative) responsible for achieving low costs in his area.

6.1.3 PER LIMITATIONS AND RESERVATIONS

NASA and industry limitations and reservations concerning development and use of PERs were too extensive to be shown in the questionnaire space provided. They are summarized below.

NASA

a. People do not read and will not use handbooks to manage programs

b. Generalized PERs will not be applicable to specific programs

c. Historical data does not tell whole story; therefore, PER conclusions becomes one man's opinion

d. Just another control from above

e. Will be much harder to establish confidence in PERs than in CERs

f. People in a position to influence NASA-wide and field center policy will not read nor use a handbook

g. Lack of (quality/quantity of historical) data to generate meaningful PERs

h. Even if low-cost practices and PERs were "perfect tools" they would not be used in must succeed programs nor where major risks are involved

i. Must have mandatory training program and strong direction from HQ to all levels of NASA management if they are to be used effectively

j. Difficult to keep PERs current to reflect low-cost progress being made

k. Inertia of high level administrative and management people will prevent usage

l. Low-cost approaches are considered to be uncomfortable and high-risk approaches

m. NASA HQ want field center managers to take more risks, but do not provide quantified direction nor clarify acceptable "consequences" relative to program success and/or individual careers

INDUSTRY

a. PERs/Handbook will not be used by industry if their use conflicts in any way with a specific RFP and/or proposal evaluation instructions

b. Historical data is meager, non-definitive and sometimes purposely deceptive and will result in questionable conclusions

c. Low-cost approaches and PERs that work well for one company will not work at all for other companies without completely reorganizing personnel and revamping company policies and procedures

d. Lack of top level support of low-cost practices results from success in previous high-cost programs and overhead practices

e. PERs must identify risk vs. cost savings to all government and industrial organizations involved

f. Different sets of PERs would have to be developed for many types of program situations

- New programs with mostly new technology
- New programs using only known technology
- New programs using standard hardware
- Follow-on programs with high inheritance
- Follow-on programs with low inheritance
- Programs requiring long-term vs. short-term operational life

g. A major limitation of PER usage will be establishment of confidence in the validity of costs associated with various program practices.

12.6.1.4 Preferred Format For PERs and Handbook

The general format preferred by survey participants is essentially the same as that developed in the previous Low Cost Program Practice Study. Line graphs, tables, bar charts and mathematical equations, in this respective order, are the formats preferred for PERs. Users instructions on separate (facing) sheets or on the face of the PER (when possible) are preferred over the concept of combining all instruction in one section of the handbook. The latter would require users to spend too much time "flipping and hunting".

Most participants preferred the use of a combination of historical data plus estimating data for generating PERs to the use of either historical data only or estimating data only. All preferred to have source data included on the PER or in the users instructions.

In retrospect the question of using historical data only for PER development could be considered somewhat impractical. Historical data can be used only to quantify traditional high cost practices. Estimating data, estimates and judgments must be used to quantify potential cost impacts of alternative low cost practices. The true value resulting from this question is that 79% of the participants recognized and accepted this situation as the preferred mode of operation.

12.6.2 Additional Comments and Observations

The following is a compilation of comments orally expressed by participants during orientation presentations and interview sessions. All of these are related to achieving low-costs in future NASA programs. Some are extensions of PER survey questions and/or answers. Some express different ideas for

achieving low-costs. Both positive and negative throughts are included because in the opinion of most participants both positive and negative actions will be required to change present practices to low-cost practices and depending on one's point of view, a specific idea can be either positive or negative.

12.6.2.1 Comments About PERs

Three out of five NASA organizations surveyed basically considered a NASA-wide PER handbook to be feasible and desirable. One seriously questioned the desirability of such a handbook but did not question the feasibility. One considered it highly desirable but seriously questioned the feasibility. This Center's experience in working with historical program data (NASA and contractor) has led to the belief that most NASA's past and present program practices cannot be accurately quantified in significant depth using the historical data available. All organizations questioned the depth, continuity and credibility of historical cost and programatic data to some extent. On the other hand, three centers felt that the PER approach is a good one and that PERs are very practical tools. These also believe that existing historical data is something less than perfect and that it will not be possible to quantify all practices using existing data. Nevertheless, they recognize that existing historical data is the only "data" available for quantifying the cost impacts of program practices. In addition, they believe that the PER handbook approach will be of great value to NASA if as much as 50% percent of the existing practices are quantified with reasonable accuracy. They believe the shortcomings in NASA cost/technical record keeping system can be identified and corrected to allow accurate quantification of practices

in future programs and continued PER expansion and refinement. In addition, they feel that the PERs generated to date are just what NASA needs to stimulate low-cost thinking and to offer challenging targets for future programs.

The PER handbook is a desirable but not sufficient tool for implementing low-cost practices. Many NASA participants feel NASA should sponsor seminars and training courses on low-cost program planning and management in conjunction with or instead of a PER Handbook. Some feel that people will not use handbooks for planning and managing programs and point out handbooks and guidelines such as NASA's Statement of Work Handbook, NHB 5800.1 and NASA's Phased Project Planning Guidelines are not now being used/implemented effectively.

Industry in general, believe a PER Handbook would be useful as a set of guidelines. However, industry emphatically states that PERs will not be used if they conflict in anyway or degree with ideas expressed in RFPs, proposal instructions, proposal evaluation criteria and/or requirements and specifications contractually imposed as direct SOW statements or by reference to boiler plate specs. In short, industry will not risk having a major proposal eliminated from competition as being non-responsive to the above contracting instruments. In cases, which frequently occur, where these contractual instruments and/or their interpretation leave doubts as to the amount of work, extent of work overlap between functional work groups, degree of check and balance and scope of reporting desired by the NASA, contractors tend to be overresponsive as a hedge against a non-responsive ruling.

The basic rationale being that NASA can negotiate out excesses proposed but cannot legally "read in" implied nor logically intended responses which are not explicitly stated in proposals.

12.6.2.2 Historical Data Comments

- Historical programatic/cost data are often incomplete and misleading which in turn creates data credibility doubts and leads to the feeling that PERs are just one person's opinion of data which can be interpreted several ways.

- Most programs evaluated to date were completed prior to 1973 and do not accurately reflect cost impacts of NASA's here and now practices which to some degree are changing toward low-cost practices.

12.6.2.3 Risk Considerations

Many NASA participants expressed the feeling that spending less and doing less on programs would automatically increase program risks. These also felt that PERs quantifying the cost impact of program practice alternatives would not be used until the risk impacts of each alternative were also quantified. Others in NASA and industry feel that many program practices can be altered without impacting risks in any way. They also believe that some practices which do impact risks can be altered to reduce both cost and risks. In addition, they point out that the degree of risk due to existing practices have not been quantified to any credible degree and that presently there is no correlation between the amount of money spent in historical programs for assurance and/or risk reduction functions to the degree of program success achieved in space operations.

12.6.2.4 Program Definition

Lack of early and complete program definition (including definition technical and management requirements, specifications to be imposed, program constraints and priorities) has been a major cost driver in most NASA programs. This belief was generally expressed by most NASA and industry participants. A few indicated that about the only thing which remains fixed after a phase C/D contractor has been selected is the program name and the costs initially estimated/negotiated (even then the name may change). Most believe that NASA should concentrate on developing better and more complete program definitions before phase C/D Request for Proposals are written and issued. Some feel that RFP development should be an integral part of NASA's program definition efforts because last minute haste in RFP preparation tends to force program waste by eliminating time for cost/worth analysis of requirements imposed, heavy reliance on boiler plate material and errors of omission. They feel that low cost practices will not be proposed unless future RFPs clearly state that they are desired and give some indication as to the extent they will be tolerated in future proposals without risk of having such proposals ruled non-responsive.

Some believe that NASA should use its program definition process, in addition to the Low Cost Systems Office (LCSO) efforts, to

a. Identify high leverage low cost practices most applicable to the program being defined,

b. Streamline/eliminate "how-to" specifications and procedures which are no longer needed or are not cost effective with respect to the program being defined,

c. Identify the minimum level of documentation, reporting and interfacing necessary for the program and the minimum cost method(s) of achieving the desired level,

d. Evaluate and quantify the need for and cost-effectiveness of using duplicate management teams and duplicate technical support teams within NASA and contractor companies for the same program,

e. Define and quantify the most cost-effective "single team concept" using a combination of NASA and contractor personnel to perform all necessary functions with a minimum of overlap and/or duplication.

12.6.2.5 SPECIFICATIONS

Common belief expressed by many industry and some NASA participants relative to reducing the cost impact of specification are:

- NASA should eliminate all specs telling contractors "how-to" do the job and issue only practical on-orbit performance specifications.

- NASA should streamline and/or eliminate specs requiring multiple tiers of over-the-shoulder checkers to police/monitor work accomplished by the initial doer and the first checker.

- NASA should constrain spec writers by having them perform cost/worth impact analysis before new specs are issued.

- NASA should also constrain the proliferation of specs being accomplished by rewording and/or combining general-off-the-shelf specs into new program-peculiar specs without making significant changes nor voiding the previous general specs. These practices are expensive. They can cost as much as $50,000 to $60,000 per spec, but add very little or nothing to the success of a program. NHB 5300.4 (ID-1) is one such example.

12.6.2.6 DOCUMENTATION

Most participants feel historical documentation practices have not only been excessive but have also been ineffective. They feel that documentation requirements are not well planned early enough nor complete enough during

Phase B activities. This lack of requirements planning not only encourages the initially proposed list of documentation to be excessive due to contractor non-compliance concerns but historically it has allowed/ encourage the total amount of documentation generated during some programs to grow by an approximate factor of two over what was initially proposed. On the other hand this practice does not provide the preplanned continuity and depth of information necessary to manage programs cost-effectively not to accurate evaluate cost and programatic impacts of technical and management decision and/or program practices from historical records.

One NASA participant observed that the total amount of documentation purchased in historical programs has been more directly proportional to the degree of government involvement (numbers of centers and people) than to anything resembling true program needs. Several others agreed with this observation and believe it is largely due to the practice of incrementally imposing/accepting documentation requirements/desirements NASA and industry people want to add for political as well as technical and management reasons. These, of course, feel that NASA should alter this practice and start imposing documentation requirements according to a well defined documentation plan for each program based on the minimum needs of the program. Recognizing that some degree of documentation is necessary for effective management and control of programs which do not get into development/operational troubles and that some additional documentation may be necessary for fact-finding and recovery purposes for programs which do experience such troubles these participants still believe NASA current documentation practices result in excessive documentation and

costs for either or both situations. Basic fixes recommended were to:

a. Develop a minimum documentation requirements plan for general use in unmanned space programs (new and follow-on) via LCSO efforts.

b. Develop minimum documentation plans for each specific program via NASA and contractor program definition efforts using the above general plan for unmanned space programs as guidelines.

c. Incorporate the minimum plan thus developed as a "not to exceed target" in the PFP's for Phase C/D portions of each program.

12.6.2.7 TESTING

The practice of pulling more test work from contractor plants to NASA centers as contract funding decreases is believed to be a minor cost driver by NASA and **several** contractors when existing test facilities and equipment can be used at both locations. The practice of performing redundant and or parallel testing at multiple locations which require additional test articles, equipment, personnel, etc., was considered to be a major cost driver in some programs.

One significant low-cost alternative suggestion relative to testing is to standardize testing equipment and instrumentation (commercially available preferred) as much as possible. Others were to design to minimize/eliminate as much testing as possible and design so necessary testing can be performed by low-cost techniques.

12.6.2.8 PERSONNEL UTILIZATION

Recognizing that at least 60 to 65% of all NASA expenditures are spent for labor and labor benefits, many participants believe NASA must develop more efficient personnel utilization practices at all levels of all NASA and Industry organizations involved in NASA programs. Although efficiency evaluation and quantifivation of NASA/Industry organizations/personnel is not an integral part of this study many participants believe it is the key to achieving more space for each NASA dollar. Some suggest that NASA Headquarters should separate NASA research functions (personnel-associated costs) from program and program-support functions (personnel-related costs) and take the lead in defining more efficient roles for all NASA personnel. They also believe more efficient roles must be defined for NASA and contractor personnel for future programs in context with the single team concept previously mentioned. The basic rationale supporting this suggestion is that talented personnel freed from desirable but semi-productive or non-essential tasks in traditional programs can be used, along with dollars saved by implementing low-cost practices to implement additional new programs within the limits of NASA "fixed budget." These participants feel that approximately 40 to 50% of NASA and Industry personnel are already motivated to buy more space per NASA dollar in this manner, but can't implement their ambitions within the existing system of controls, constraints, habits and practices. One observation commonly expressed is that in small programs, motivated people are successfully implementing short cuts and some low-cost practices without increasing risks. This brings up the question of why can't the same or even greater variances from traditional practices be implemented in large programs with comparable success?

12.6.3 CONCLUSIONS

6.3.1 HISTORICAL DATA FOR PER's

a. Based on the historical data LMSC has analyzed to date and inputs from survey participants, NASA historical programatic/cost data is not adequate to quantify a full set of PER's covering all major cost deriving practices.

b. Historical programatic/cost data is frequently incomplete, inconsistent and misleading due to previous record-keeping practices used in all phases of programs.

c. Historical data from programs completed prior to 1972-1973 if used as a base for PER's, would not include cost reductions being incorporated in more current programs due to tight budget constraints.

d. Only 18% of the survey participants believe the historical data available in their center/company is adequate for generating meaningful (accurately quantified) PERs and LMSC experience to date supports this opinion as a basic conclusion.

12.6.3.2 PERs and PER Handbook

A. The PER/Handbook concept is basically a good one but the present state of NASA's historical data and the general lack of confidence (NASA and Industry) in existing historical data tend to preclude quantification and acceptance of PER's covering most of NASA's high-cost driving practices at this point in time.

B. LMSC concurs with the general belief expressed by survey participants that if a perfect and complete PER Handbook could be generated at this time is use alone would not be adequate for implementing low-cost program practices even though it could be a very useful tool in conjunction with training programs and seminars.

C. To effectively cover the scope of future of NASA programatic situations currently envisioned, different sets of PER's would have to be developed which would isolate and quantify individual practices and the interrelationships between practices for:

- o New programs with mostly new practices
- o New programs using only known technology
- o New programs using standard hardware
- o Follow-on programs with high inheretance
- o Follow-on programs with low inheretance
- o Programs with long-term versus short term operational life
- o Programs with refurbishable hardware vs throw away.

D. Both cost and data constraints preclude generation of PER's for the above programatic situations at this time.

E. Generation of PER's as they are presently conceived and defined should be discontinued for the present in favor of alternative approaches which could have more wide spread acceptance and be more cost-effective for NASA near term transition toward low-cost practices.

F. Many historically high-cost driving trends associated with various program practice areas can be adequately identified and alternative corrective actions can be successfully identified and implemented without using PER levels of quantification.

12.6.3.3 Preferred PER/Handbook Format

The preferred format(s) for PER's and a PER Handbook is basically the same as that generated in the previous LCPP study (LMSC D387518). This information could be of value if and when PER development is resumed.

12.6.3.4 RISK Considerations

A. Risk considerations are now and will continue to be a major concern with respect to NASA's implementation of low cost practices.

B. Survey participants from industry tend to disagree with the somewhat general NASA belief that risks will automatically increase if any low cost practices are implemented.

C. The requirement frequently stated/implied by NASA personnel that risks must be accurately quantified for each potential low-cost practice before PER's would be used or low cost practices would be implemented is judged to be a natural delaying type response to changes in the existing status quo of program operations. Students and layman some-

what versed in the Transactional Analysis theory of psychology recognize this "requirement" as a response from one's child-ego-state instead of his adult-ego-state. In effect it says, "I will do your difficult and seemingly impossiblle task if you will do an even more difficult/ impossible task first".

D. The idea of quantifying risk impacts as well as cost impacts of potential low cost practices is not considered practical. Historical risk impacts have not been quantified nor recorded as well as cost impacts have.

E. Risk impacts of alternative practices should be evaluated as soon as possible at the judgmental level and where practical at the quantification level.

F. Until demonstrated otherwise, industry will be concerned with the risk of NASA's spending less money for less space programs instead of spending the same level of dollars for more space programs after low cost practices are successfully implemented.

12.6.4 Recommendations

*A. Discontinue development of PER's at this time.

*B. Start immediate development of a Work Breakdown Structure which will allow program practices to be accurately quantified in future space programs.

*C. Start efforts to evaluate risk impacts of potential low cost practices identified to date at the judgmental level supported by estimated and/or historically sustaniated examples were possible.

D. Use potential low cost practices identified in this and other studies in future RFP's to get additional cost and risk data estimates during phase B and phase C/D proposals.

E. Continue quantification of historical program practices using in-house NASA personnel (or LMSC personnel if sufficient data is made available) to quantify the cost impacts to the extent NASA's historical data allows (not necessarily PER level) and to identify shortcommings of NASA's historical record keeping practices. (Industry legally can and will make more meaningful data available for NASA use than for a potential competitor.)

F. LMSC recommends NASA follow up on this PER Survey by implementing an Aerospace Executive Level Survey on Low Cost Program Practices. The main thrust of this survey would be to:

- o Determine if wide spread agreement or disagreement exists between the Vice President and Center Director levels and the levels of the "working level manager" who, in responding to this survey furnished the answers, which present the summary opinion of 43+18= 61% who believe individual program cost reductions of 25 to 50% could be obtained by implementing low cost practices.
- o Obtain an executive level "feel" for which practice areas (documentation, specifications, program definition, contracting practice, overhead practices, accounting practices, etc.) could be reduced without significant risk impacts if NASA's (and maybe DOD's) practices were altered/streamlined to eliminate unnecessary/excessive requirements and procedures.

- o Obtain their personal "feel" for how much could be saved in each practice area.

G. Results of this survey, results of the LCPP Study to date and the results of low cost program/management practice studies such as the 1974 EOS study are recommended as inputs for generating an Orientation Brochure and Survey Questionnaire if recommendation F is implemented.

H. Implementation of an educational/promotional effort is recommended to assure NASA field centers/industry that NASA fully intends to buy more "new" space programs with dollars saved by implementing low cost practices.

* These recommendations were made during the mid-term study review and are being acted upon by NASA.

ENGINEERING MEMORANDUM

TITLE:	EM NO: LCPP-13
SPECIFICATION ANALYSIS, MIL-D-1000	REF:
	DATE: August 26.1975
AUTHORS:	APPROVAL:
H K Burbridge.	ENGINEERING H K Burbridge SYSTEM ENGRG D L Hannaford

1.0 General: As a task of the current Low Cost Program Practices Study, LMSC has re-written the specification MIL-D-1000; Engineering Drawings and Lists. This document was subjected to detailed analysis prior to the actual re-write activity, to determine its impact upon aerospace programs, in terms of cost-driving considerations, and general applicability. The re-write task was approached on the basis of the outcomes of the detailed analysis forming the structure for the Low Cost version of the specification. So that NASA users of the Low Cost version of the specification may be aware of the factors influencing the re-write, these factors, and the results of their study are given in the following text.

2.0 Applicability of MIL-D-1000 MIL-D-1000 has been the drawing specification invoked routinely for the majority of DoD and NASA contracts undertaken in the aerospace industry since 1957. The document, in its present form instructs contractors in the manner in which drawings prepared for the US Government are to be executed, In itself, the document is neither long, nor highly detailed, yet is is an extremely complex document. The complexity arises from the fact that it invokes many other sub-tier specifications and standards, both military and industrial. The quantity of sub-tier specifications invoked is dependent upon the Form requirement imposed by MIL-D-1000, and one or more of ten categories of drawings that the government may require to be produced. The Forms cited in the document are 3 in number, and are as follows:

- o Form 1 requires: Full Military Compliance/Control
- o Form 2 requires: Partial Military Control
- o Form 3 requires: Drawings to Industrial Standards with Minimum Military Controls.

The categories, 10 in number are as follows:

A. Design Evaluation Drawings

B. Interface Control Drawings

C. Service Test Drawings

D. Logistic Support Drawings

C. Procurement Drawings (Identical Items)

E. Procurement (Interchangeable Items) Drawings

F. Installation Drawings

H. Maintenance Drawings

I. Government Manufacture Drawings

J. Interchangeability Drawings

MIL-D-1000 defines all these categories, and the 3 Forms, and states that the Government will define, and specify, per each procurement from a contractor; the Form(s) and category(ies) under which the drawings are to be prepared.

Figure 2.1. details the Document Dependency Listing for all tiers associated with MIL-D-1000 and is given for information.

For space programs undertaken by both DoD and the NASA, the usual Form imposed has been Form 2, as experience with Form 1 has demonstrated that production to the full requirements invoked is too costly. Costs do not vary very much from category to category, and it is clearly evident from the analysis undertaken that the cost driving aspects of MIL-D-1000 lie in the Form invoked.

In application of MIL-D-1000 to space programs, research indicates that the drawings produced under Government contracts do not vary very much in <u>nature</u>, whether Form 1, 2, or 3, is called out. The symbology used is much the same, and the

MIL D 1000 Sub-Tier Specifications

		Form No.
Federal Specs:		
UU-P-00561...	Paper, Tracing.	(2)(3)
CCC-C-531 ...	Cloth, Tracing.	(2)
Military Standards:		
MIL STD 100A...	ENGINEERING DRAWING PRACTICES (Cost Driver)	(2, parts only)
MIL-STD-143 ...	Order of precedence, specs, stds.	(2)
MIL-STD-9......	Screw Threads	
MIL-STD-12C....	Abbreviations	
MIL-STD-14.....	Architectural Symbols	
MIL-STD-15.....	Electrical Symbols	
MIL-STD-17.....	Mechanical Symbols	
MIL-STD-18.....	Structural Symbols	
MIL-STD-29.....	Springs, Mechanical.	
MIL-STD-34.....	Optical Elements	
MIL-STD-275....	Printed Wiring	
MIL-STD-806....	Logic Symbols	
Industrial Standards:		
USAS B46.1 -62	Surface texture, roughness, waviness & lay	
USAS Y14.5 -66	Dimensioning & tolerancing for engrg dwgs	
USAS Y14.15-66	Electrical & Electronic Diagrams	
USAS Y 32.2-67	Graphic Symbols for Elec & Electronic diagrams	
USAS Y32.16-65	Electrical & Electronic Reference Designations	
AWS STD A2.0-58	Welding Symbols	
AWS STD A2.2-58	Non Destructive Testing-Welds.	
Mil-Specs:		
MIL-D-5480.....	Data, Engrg & Technical, reproduction of:	(2)
MIL-Q-9858A....	Quality Program Requirements	(2)(3)
MIL-M-9868.....	Microfilming Engrg Dwgs	*(2)
MIL-I-45208....	Inspection System Requirements	(2)(3)
MIL-C-45662....	Calibration of Measurement & Test Equipment	(2)
MIL HDBKS:		
H4-1...........	Federal Supply Code; Name to Code	
H4-2...........	Federal Supply Code; Code to Name	
H6-1...........	Federal Items Identification Guide	(2)
H7.............	Mfrs Part & Dwg Numbering System	(2)
Mil Manuals:		
5220.22M.......	DoD Industrial Security Manual	(2)(3)
4120.3M........	Standardization; Policies, Procedures & Instructions.	

All the documents listed above are invoked by imposition of MIL-D-1000.Form-1.

(2) denotes Form 2 only.

(3) denotes Form 3 only.

* Only if Requ'd by CDRL

Fig.2.1.

differences arise from the degree of assurance applied to certify compliance with the drawing requirements invoked. One of the difficulties arising from application of MIL-D-1000 to aerospace programs emerged clearly from this analysis, and can be described as the lack of understanding by technical personnel at contractors' plants, of the entire MIL-D-1000 and its sub-tiers assemblage of documents. A similar lack of understanding was exhibited by Government employees, with whom the subject was discussed. Such a lack of understanding is scarcely surprising in the light of the fact that should Form 1 be invoked 38 sub-tier documents are involved, for Form 2 the number drops to 12, and for Form 3 only 4 sub-tier documents are involved.

In considering the applicability of MIL-D-1000 to space programs using either conventional , or standardized hardware components, or both; the question arose: "Why not use Form 3, as the least costly, and least difficult Form to apply". The answer appears to be that the NASA would not be able to differentiate as to costs between Form 2, and Form 3, and would in all probability, be paying Form 2 prices, for Form 3 drawings. This condition would arise from the fact that aerospace contractors are accustomed to work to Form 2, and the majority of Drafting Practice Manuals (DPM) have been structured about Form 2 requirements, and the major sub-tier document MIL-STD-100A, Engineering Drawing Practices. Even Form 3 costs are augmented by the mandate that compliance with MIL-Q-9858A is contractually binding upon the contractor.

The conclusion was reached that the MIL-D-1000 document with its sub-tiers is neither a Least-Cost promoting specification, nor is it directly applicable to NASA needs for space programs. This conclusion prompted the LMSC rewrite of the document.

3.0 Open Ended Specification Requirements & Practical Requirement Limitations: The present MIL-D-1000 specification tends to be open ended. In effect, unless a contractor possesses all of the sub-tier documents cited in the prime specification he could not produce an acceptable drawing. MIL-STD-100A, the major sub-tier document defines, with examples,how a drawing is to be produced, titled, lettered, bordered, detailed, etc., etc., etc. In turn, MIL-STD-100A, calls out those regulating documents which the DoD believes essential for the reproduction, microfilming, preservation, packaging, shipping, etc, of drawings produced for the Government. MIL-D-1000 merely categorizes the drawings by classification of end-use, and specifies the rigor of the control measures to be applied to the various levels as defined. Whenever the Government so elects, drawing measures can be augmented by special provisions within the RFP, and these must be observed by a contractor, if he is not be be adjudicated non-compliant.

In terms of practical requirement limitations, LMSC is of the opinion that requirements should be made a simple as possible if costs are to be maintained at some minimum level. Further, all pertinent information concerning drawings should be included in one document, as far as possible. Finally, assurance functions undertaken to determine compliance with specified requirements should be maintained at an irreducible minimum, to obviate"checkers for the checkers". These factors have been recognized, and treated in the re-write of MIL-D-1000.

4.0 Requirements vs State of the art Relationships: As stated in paragraph 3.0, MIL-D-1000 does not specify methodology for the preparation of drawings. It cites instead MIL-STD-100A for that purpose. This Standard, while elaborately detailed, and inclusive of many samples of drawing requirements for lettering, et al; is outmoded in the light of current aerospace requirements.

The document does not contain information pertinent to electronic microcircuits, nor are references made to computer produced drawings, or other mechanical aids to drafting such as "Paste-Up" superimposable symbols, letters, and other forms of decals. All of these data are included as part of the revised specification generated to be a Low Cost replacement for MIL-D-1000.

5.0 Functional Division of Contract Labor: The production of drawings and lists compliant with MIL-D-1000 involves the following segments of contractor direct labor:

- o Design Engineering/Design Drafting
- o Quality Assurance, Engineering and Inspection.
- o Configuration Management, and Configuration Control.

Research into several NASA programs indicated that costs of direct labor in these three areas can be appreciable in the first two. The cost impact on drawing production of Configuration Management, does not appear to be great, at least on the two programs considered, MVM-73 and AE. The details of these impacts, on direct labor costs were the subject of two previous EMs to which reference should be made for further information on the subject. These EMs are:

LCPP-2. Impact of MIL D 1000 Upon Space Programs, and Proposed Cost Improvements of Changes. Jan 7/75

LCPP-3. Potential Cost Benefits Derivable From Changes to 10 Selected Cost Driving Specifications. Jan 14/75.

LCPP-2 includes a summary chart which is repeated in this EM to illustrate,(Fig 5.1) the program costs involved in making drawings to Forms 1,2,&3, and the high contrbution of Quality assurance to these costs. In addition, if it is assumed that Form 3 drawings can be produced for some unit cost, then:

Form 3 Drawing Costs = 1, Form 2 Drawing Costs = 1.4 approx. Form 1 = 1.75,

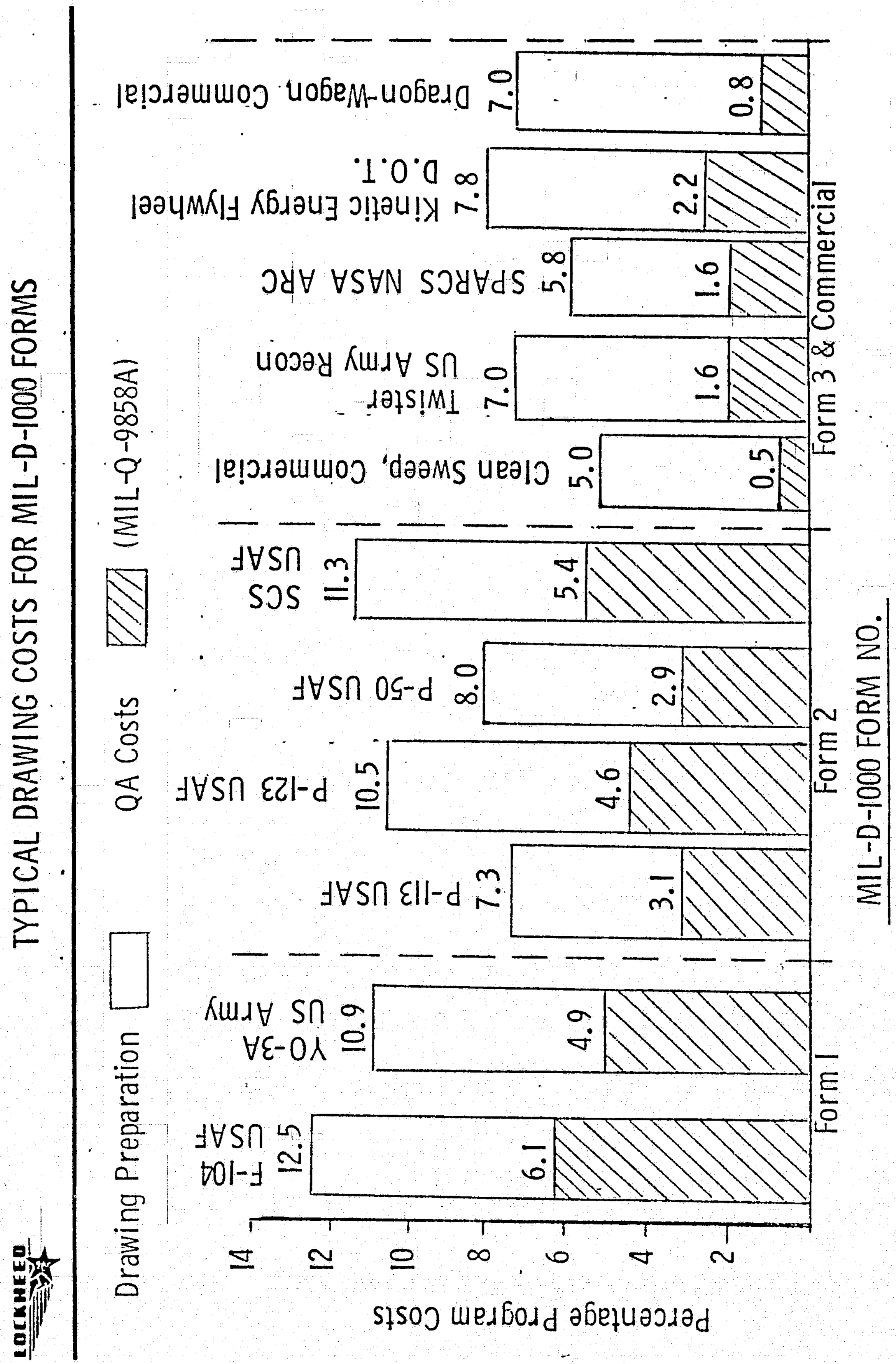
LOCKHEED
TYPICAL DRAWING COSTS FOR MIL-D-1000 FORMS
Drawing Preparation
QA Costs
(MIL-Q-9858A)
Percentage Program Costs
14
12
10
8
6
4
2
F-104 USAF
12.5
6.1
YO-3A US Army
10.9
4.9
P-113 USAF
7.3
3.1
P-123 USAF
10.5
4.6
P-50 USAF
8.0
2.9
SCS USAF
11.3
5.4
Clean Sweep, Commercial
5.0
0.5
Twister US Army Recon
7.0
1.6
SPARCS NASA ARC
5.8
1.6
Kinetic Energy Flywheel D.O.T.
7.8
2.2
Dragon-Wagon Commercial
7.0
0.8
Form I
Form 2
Form 3 & Commercial
MIL-D-1000 FORM NO.

Fig 5.1

As has been stated previously in Pargraph 2.0 of this EM, Form 3 costs for the production of drawings are not Least Costs, as quality provisions are still required, and most DPMs in use by contractors are modelled after Form 2, and even Form 1 requirements to some extent. The LMSC re-write is oriented toward Least-Cost Practices, and treats methods of lowering the cost below those applicable to Form 3.

6.0 Specification and Requirement Overlaps: LMSC has found, that in the course of studying specifications, there are numerous documents whose requirements overlap. An example would be MIL-Q-9858A Quality Assurance Provisions, which to an extent overlaps the requirements set forth in MIL-I-45208 Inspection Systems For Aerospace Contractors. In the case of MIL-D-1000there are no overlapping requirements contained in other specifications, since MIL-D-1000 deals with the general requirement for the preparation of drawings for delivery to the Government, whereas MIL-STD-100A and others deal with Engineering Drawing Practices.

7.0 Contractors Probable Response to RFPs and Associated Specifications Lists: To combat response by contractors to the Form 3 requirements of MIL-D-1000 with Form 2 level costs, LMSC believes that the following measures must be instituted by NASA.

1. Impose the rewritten version of the drawing specification.
2. Be highly specific as to exactly what is expected of the contractor(s) using the RFP and other contractual documents as vehicles for this purpose. Any deviations from the drawing specification should be detailed in these documents as applicable.
3. Ensure that contractor(s) DPMs be revised to reflect Low Cost Practices, before the DPMs are approved, and make such approval a binding condition of each contract.

4. Assure that drawing costs are monitored per contract, and that such costs are isolated as a cost entity separate from the overall costs of documentation.
5. Coordinate the Low Cost aspects of the rewritten specification replacing MIL-D-1000,with the NASA & Tri-Service Specification Review Board. This measure will facilitate any cost saving measures recommended by the DoD being incorporated into the final drawing document.

8.0 General Specification Changes: At the outset of the specifications analysis task there was agreement between NASA/HQ and LMSC that a listing of the changes recommended to any specification under study would be made. This listing would serve as a basis of comparison for the specification under study, as written, versus the cost saving aspects of the changes. An example of this technique was the analysis and evaluation of NHB.5300.4(1B) Quality Assurance Provisions; which formed the subject matter of EM LCPP-6 issued February 24/75.

In the case of MIL-D-1000 changes to the document structure, and provisions/requirements were of such a major nature and extent, that no such list could be considered practical. LMSC undertook therefore to generate a completely new specification, the draft of which was submitted to NASA August 20/75, for review and comments.

9.0. Cost Effectiveness of Changing and/or Eliminating Sub-tier Specifications. Figure 2.1 shows the specifications associated with MIL-D-1000 for the three Forms. The rewite of the drawings specification preparated by LMSC eliminates all sub-tier specifications previously invoked by MIL-D-1000, and uses only 4 documents in support of the new specification. Of these,three (3) are used as references and guides; viz: MIL-STD-100A where necessary, MIL-M-9868 Microfilming, and MIL-D-5840 Preparation of Data for shipment to the Governement, also only where necessary. The only document imposed is 5220.22M, the DoD Industrial

Security Manual, which sets forth the measures to be taken to protect the Government's rights to security. This document too, would only be used in cases where classified drawings were to be produced.

The new drawing specification is believed to be Cost Effective since:

- o All sub-tier documents save those cited above have been eliminated as mandatory inclusions, and those cited are to be used as references and guides.
- o Document acquisition and reading time have thus been greatly reduced.
- o The tracking of specification changes, and their incorporation into the specifications to which these changes relate, has been reduced, by the elimination of the sub-tier documents.
- o Confusion caused by the proliferation of the number of inter-related specifications, has been reduced by greatly reducing the number of such documents, which in turn lessens the chance of document misinterpretation.

All these factors contribute to saving time expended by technical personnel, and LMSC studies have demonstrated that the greatest cost to NASA is "People Dollars" both within the NASA organization, and at contractors' facilities.

Lockheed Missiles & Space Company

ENGINEERING MEMORANDUM

TITLE: IMPLEMENTATION COMMENTARY, MIL-D-1000	EM NO: LCPP-14 REF: DATE: AUGUST 28.1975
AUTHORS: H K Burbridge	APPROVAL: ENGINEERING SYSTEM ENGRG D L Hannaford DLHannaford

1.0 General: As a task of the current Low Cost Program Practices Study, LMSC subjected MIL-D-1000 Engineering Drawings & Lists to intensive analysis to determine its cost affecting consequences when applied to NASA space programs. The outcomes of this analysis, documented in EM LCPP-13 Specification Analysis MIL-D-1000, were (a) a decision to re-write the specification, and (b) furnish an implementation commentary on the new specification, to facilitate its application and use.

2.0 List of Changes: A list of changes is as follows:

(1) Forms 1,2 &3 of the MIL-D-1000 specification were eliminated, the new document requiring a level of control even less than that of the old Form 3.

(2) The number of categories was reduced from 10 in the MIL-D-1000 to 3 only in the new one. New categories are:

- o Design Descriptive/disclosive
- o Procurement
- o Installation & Maintenance.

(3) Every MIL-STD and MIL-Spec was eliminated from the sub-tier of MIL-D-1000 documents except one. This one 5220.22M was retained in order to protect the Governments rights to security. The document is the Industrial Security Manual.

(4) MIL-STD-100A Engineering Drawing Practice, and its associated Industrial standards were cited as references and guides only, to be used in those cases where contractors' Drafting Practices Manuals (DPMs) are not considered adequate by NASA.

(5) Contractors' DPMs were cited as the regulating documents for drawing production, subsequent to approval by NASA.

These are the major changes, the minor changes are contained in the detailed re-write of MIL-D-1000 which is tentotively titled <u>A Low Cost Engineering Drawings and Lists Specification</u>.

3.0 <u>Potential Implementation and Interface Problems</u>: At the outset of the specification task there was some concern that the adoption of a new, and considerably simplified drawing specification might cause some implementation problems. So far as may be determined currently, a problem might arise from contractors charging NASA Form 2 prices for drawings produced to the requirements of the new specification. This problem is discussed at length in both EM LCPP-13 aforementioned, and the new specification itself, together with the measures to be observed in preventing such a condition. The condition is believed to be of a temporary nature, and will decrease, or be eliminated as contractors become familiar with working to the new document. No other problems of interface/implementation are forseen.

4.0 <u>Scope of Savings Anticipated When New Document is Implemented</u>: During the course of the LCPP Study, cost savings to be derived from re-write and simplification of MIL-D-1000 were studied extensively. Results of the study were documented in depth in the following EMs:

- LCPP-2 <u>Impact of MIL-D-1000 Upon Space Programs and Proposed Cost Improvements of Changes</u>. Jan 7.1975
- LCPP-3 <u>Potential Cost Benefits Derivable from Changes to 10 Selected Cost Driving Specifications</u>. Jan 14.1975
- LCPP-13 <u>Specification Analysis, MIL-D-1000</u> August 26.1975
- The rewritten specification itself.

A short summary of the results may be given as follows:

Assuming some nominal cost to a program associated with production of drawings to the Form 3 requirements of MIL-D-1000, then the same drawings produced to Form 2 would cost approx. 40% more, and drawings to Form 1 requirements would cost approx.75% more.

Conversely, Form 3 represents a savings of 57% of program costs for drawings vs Form 1. These,and other drawing cost data are given in the referenced EMs. In addition to the cost savings afforded by adoption of Form 3, LMSC believes that further cost benefits may accrue from adoption of the re-written Low Cost Drawing specification. Currently, there is no precedent for such a statement, as there has been no program exposure to the re-written specification, but discussion with LMSC SSD Chief Draftsman, and LMSC manufacturing representatives has elicited the opinion that a savings ranging from 5-8% of the costs incurred in producing drawings and lists to Form 3 requirements may be expected. This opinion is based largely on the use of sketches, and pencilled lines only in the R & D engineering phases, and the minimization of drawing changes. Such savings might not accrue immediately following adoption of the new specification, as there may be minor costs in simplifying contractors' DPMs, and re-orienting drafting personnel.

5.0 Risk Considerations: In terms of the classic definitions of Program Risk; i.e. Risk to Hardware Performance, Risk to Maintaining Program Schedule, and Risk of Incurring Additional Program Cost, LMSC forsees no risk increment in any of these areas. Since LMSC believes that personnel drafting time will be saved by imposing the new drawing specification on programs, risk to schedule, and program cost should decrease, if anything.

6.0 New Drawing Specification & Contractors' Low Cost Responses:

The Low Cost Drawing Specification, in its present form, contains rationale for the changes made to improve costs beyond the Form 3 mandates of MIL-D-1000. A background of the history of the MIL-D-1000 document also is included for those unfamiliar with the document, and its requirements. The new specification is arranged in such a manner, that all of this rationale and history can be omitted without disturbing the actual textual matter of the specification. Should NASA elect to issue the specification with the rationale deleted, the document would appear to be relatively innocuous. In this case, NASA should not only cite the new specification in the contractual section of an RFP, but also require responding contractors to comply with the specifcation, and in addition, require the contractors to include in their proposal any cost saving measures they deem applicable, over and above those required by the specification. With any new specification, there is a period during which its impact is not fully understood and accepted for what it purports to accomplish. By means of the RFP, ocntractors can be encouraged to think Low Cost, and required to furnish cost saving methods, and procedures.

Should NASA elect to furnish the Low Cost Drawing Specification to contractors, and impose it in its entirety, a precedent will be set. Currently, specifications do not contain the "Reasons Why" what is specified is included in the text of the documents. As such, they are often sterile, treating only "Dos and Don'ts". If reasons are given for some of the specific requirements, more visibility is afforded to the contractor, allowing him to use his expertise in making cost effective decisions.

LMSC emphasizes strongly the need to use the RFP as an instrument to convey to the contractor exactly what is needed as early in a program as possible.

Lockheed Missiles & Space Company

ENGINEERING MEMORANDUM

TITLE: ASSESSMENT OF RISK IMPACT - LOW-COST PROGRAM PRACTICES	EM NO: LCPP-15 REF: DATE: 8 October 1975
AUTHORS: Dale Hannaford Wayne Miller	APPROVAL: D. J. Hannaford Wayne Miller

62-02 Space Systems Division

Total Pages: 1 thru 13
A-1 thru A-52

INTRODUCTION

Under Contract NAS W-2752 to NASA/HQ Low Cost Systems Office, LMSC is performing a Low Cost Program Practices Study. Previous tasks in the study had identified certain low-cost practices which, if implemented by NASA, could result in significant savings in contractor costs.

In preliminary review of the low-cost practices with NASA Program Managers, some evidenced a feeling that implementation of the practices would increase the program risks. This task, involving the qualitative evaluation of risk impact for each identified low-cost practice, was therefore performed by LMSC to provide additional basis for NASA decisions on whether to implement the practices in general and/or on specific programs.

The basic subtasks which comprised the total Risk Impact task as described in the LMSC Technical Proposal, LMSC-D426636, par. 5.2.6.2, and as modified by coordina- with the Low Cost Systems Office, were:

(a) Establish a list of Low-Cost Practices with brief definition
(b) Catalog each practice, qualitatively, as "increased","no-change", or "decreased" risk (compared to historical practice which is replaced)
(c) Develop and explain the rationale for the risk assignment to each low-cost practice
(d) Identify the type of data required/desired to allow later quantification of the risk impact. Outline a plan for (1) tracking of cost and risk impacts as a result of implementing low-cost practices and (2) acquiring data necessary to quantify the cost and risk impacts.

This engineering memo presents the data on the risk assessment analysis, combining items (a), (b), and (c) above. Work on item (d) is continuing.

For ease of reference, all of the data have been formatted on a set of Data Sheets, each sheet covering a specific low-cost practice.

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GLOSSARY OF TERMS

Cost Impact - The cost impact is the cost-reduction effect which implementation of the low-cost practice has upon contractor program costs. The terms "High", "Moderate", and "Low" as used on the data sheets herein are relative only and indicate the general degree of cost-driver characteristic for each named practice. For example, a "High" rating of cost impact for Engineering indicates that contractor average engineering costs can be reduced significantly if the practice were applied to a program(s).

Component - A component as used herein is an assembly or a black box; examples: Star Tracker, Transmitter, Valve Assembly, Tape Recorder.

Part - A part as used herein refers to a piece-part; examples: transistor, bearing.

Subsystem - A group or set of components with interconnects of electrical cabling or piping and representing a functional portion of the total spacecraft; examples: Communications Subsystem (comprising transmitters, receivers, antenna, etc.), Electrical Subsystem (comprising batteries, solar arrays, power control unit, etc.).

Risk, Delta - The delta risk designated on the data sheets represents the potential change in risk (from the risk inherent with the historical practice) if the alternate low-cost practice is implemented. Example: a "decrease" risk designator for a practice under "Performance" indicates that implementation of the low-cost practice will decrease the uncertainty that the planned mission performance will be attained.

Risk, Cost - Cost risk is the general probability that costs will grow beyond those estimated or targeted for the program; increased cost risk represents increased probability that the program costs will overrun.

Risk, Performance - Performance risk is the general probability that the planned hardware mission performance will not be attained.

Risk, Schedule - Schedule risk is the general probability that the planned schedule will be exceeded or deviated-from in a manner which will have an influence on increasing cost or not meeting a critical milestone. For example, if the hardware completion date is keyed to a single available launch window, any increase in schedule span (non-recoverable) can be critical to the program.

ATTACHMENTS - Risk Impact Data Sheets

RFP's

LCP No. 1-1 Emphasize Complete Definition of Program Elements in Phase C/D RFP
1-2 Preliminary Review of RFP by Contractor
1-3 Use RFP to Encourage Lower-Cost Response
1-4 Streamline Response Data Required by RFP
1-5 Emphasize Minimum Acceptable Mission/System Performance Reqts. in RFP
1-6 Lower-Cost Alternate Proposals
1-7 Reduce Requirements for Contractor Plans in RFP's

DESIGN

2-1 Minimum-Cost Design Requirments for Spacecraft and Experiments
2-2 NASA Low-Cost Design Handbook
2-3 Use Flight-Proven Hardware
2-4 Use of NASA Standard Components
2-5 Lower-Cost Design Requirements for Subcontractor/Supplier Equipment
2-6 Higher Design Margins-Less Testing
2-7 Lower-Level Requirements for Secondary Experiments
2-8 Standardized and Common-Usage GSE

DOCUMENTATION

3-1 Use Low-Cost-Driving CDRL's
3-2 Documentation-Need Evaluation Form
3-3 Establish a Central Documentation Control Function
3-4 Use Direct Contact in Lieu of Paperwork
3-5 Use of Contractor Internal Documentation
3-6 Lower-Cost Engineering Drawings for NASA Unmanned Space Programs
3-7 Data Bank to Identify Documentation Costs and Cost Reduction Areas

MANUFACTURING

4-1 Increased Use of Simplified Tooling
4-2 Use of Contractor/Subcontractor Proven Manufacturing Processes

PROGRAM DEFINITION AND CHANGES

5-1 Emphasize Earlier and More Complete Program Definition
5-2 Program Definition Assessment Check List
5-3 Establish Minimum Change Policy During Phase C/D
5-4 Provide Incentives for Minimizing Cost-Increase Changes
5-5 Low-Cost Program Practice Check List

PROGRAM MANAGEMENT

6-1 Low-Cost-Oriented Program Staff
6-2 New Set of Low-Cost CER's
6-3 Small Program Teams and Minimum Interfacing
6-4 Visibility of Program Practice Cost Impact
6-5 Standardized Cost/Schedule Control Systems
6-6 Standard WBS and Definitions for Cost Elements
6-7 Common Cost Data Bank (Cost Records)
6-8 Experiment Interface Improvement
6-9 Reduce Program Hardware Traceability Requirements

ATTACHMENTS - Risk Impact Data Sheets (Contimued)

QUALITY ASSURANCE

LCP No.
- 7-1 Rewrite of QA Specification
- 7-2 Use of Contractor Quality Manual-Low Cost Version
- 7-3 Lower-Cost Material Review
- 7-4 Reduce QA Effort on Previously-Qualified Hardware
- 7-5 Reduce Quantity of Inspection Points

RELIABILITY, MAINTAINABILITY, SAFETY
- 8-1 (No data sheets; reserved for later additions)

SPECIFICATIONS
- 9-1 Revision or Rewrite of Current Specs to Low-Cost Versions
- 9-2 Cost-Effectiveness Analysis of Spec Applications
- 9-3 Do Not Apply General Specs to Contractors
- 9-4 Establish Central Spec Control and Coordination
- 9-5 Use of a Reduced "Standard" Spec List

TESTING
- 10-1 Optimize Testing for Minimum Cost
- 10-2 Test Software and Equipment Standardization

ASSESSMENT OF RISK IMPACT
LOW-COST PROGRAM PRACTICES

1. BACKGROUND

Many NASA personnel have expressed the feeling that application of low-cost practices (spending less and/or doing less on programs) would automatically increase program risks. Others in NASA and industry feel that many program practices can be altered without impacting risks in any way. The major purpose of this comparatively small task is to provide the initial countering auguments to show which of the array of low-cost practices can be implemented at essentially no increase of risk to a program.

Because historical risks had never been quantified, it was necessary to approach the low-cost practice risk comparison on a qualitative rather than on a quantitative basis. LMSC has focused the effort on providing a rationale for each low-cost practice, explaining why there is a probable increase, decrease, or no change in the program risk as compared to the historical practice.

2. BASIC TASK APPROACH

The steps in the analysis comprised: consolidate all of the potential low-cost practices into a single listing, categorizing them into groups, and providing an assignment of risk potential as compared to the historical practice. Quantification of the cost impact and of the risk impact of low-cost practices is not considered practical at this time. Therefore, a qualitative analysis has been made and the risk delta designated.

The practices listed herein are applicable to expendable-booster-launched spacecraft and can be applied to near-future NASA programs. However, all can be applied to the unmanned spacecraft of the Shuttle era also. Those additional low-cost practices which can result with use of the Shuttle have not been addressed here.

The low-cost practices listed are principally those which NASA can implement directly or indirectly in establishing program requirements which will allow reduction in contractor program responses and contractor costs.

The areas of program risk that have been used for this initial analysis are Hardware Performance, Program Schedule, and Program Cost Overrun.

It is anticipated that NASA will, after review and embellishment of the initial data contained herein, prepare and issue separate implementation directives for all or portions of the practices listed. The basic intent, therefore, in this first effort was to establish the basic framework upon which a complete listing of low-cost practices could be built over a period of time and the risk concepts made a little more tangible.

3. LISTING OF LOW-COST PRACTICES

3.1 Selected Categories

For convenience of reference, the listed low-cost practices have been grouped into 10 categories. Each Data Sheet (attachments to this engineering memo) is identified with the category number and a dash number; for example, "LCP No. 3-1" is the first data sheet under Documentation category.

The categories selected for this initial listing are:

(1) RFP's (and Contracting Practices)
(2) Design (Spacecraft, Experiments, GSE)
(3) Documentation
(4) Manufacturing
(5) Program Definition and Changes
(6) Program Management
(7) Quality Assurance
(8) Reliability, Maintainability, Safety
(9) Specifications
(10) Testing

3.2 Limiting of Practices Listed to Significant Cost-Drivers

Because of the desire to emphasize high or moderate-level cost-driver practices, many of the lesser-impact practices were omitted from the listing.

3.3 Use of NASA Practices Which Impact Contractor Costs

By agreement with the Low Cost Systems Office, the practices included in the listing are those NASA practices which impact the contractor program cost. Although a number of "internal" contractor and internal NASA practices were reviewed, they were not included on the listing; actually, they are beyond the agreed-upon scope of the current LMSC study. It seems moreover that most of these internal practices are a secondary effect of implementing the principal NASA/contractor interface requirements; the internal practices will tend to change when the prime-driver NASA requirements are altered to low-cost.

3.4 Design Practices

Most of the practices listed in the "Design" category address the general aspects of the engineering approach but do not include all of the specific recommendations for low-cost design of spacecraft/experiments/GSE. An expansion of the basic list, with embellishment, could be the base for a Low-Cost Design Handbook; preparation of such a handbook is recommended on Data Sheet No. LCP 2-2 as a new NASA low-cost practice implementation tool.

3.5 Impact of Reliability, Maintainability, Safety Practices

Our preliminary listings of low-cost practices included several for this category. Subsequent review of specific practices indicated that the cost impact was not significant for any single practice on typical unmanned space programs. We feel that this category deserves continuing attention, however, and have maintained it in the listing for possible later addition of specific low-cost practices therein by NASA.

3.6 Manufacturing Practices

Because most of the manufacturing practices are internal to the contractor and not directly impacted by the basic NASA requirements, this category has only two Data Sheets therein. In general, review of several historical NASA hardware program RFP's indicates little specific attention to manufacturing requirements. It may be that there are no additional significant cost-driver practices which can be influenced by NASA requirements upon the contractor. Nevertheless, the category has been retained in the listing for possible later add-ons by NASA.

3.7 Consolidation of Low-Cost Practices for Data Sheets

A considerable amount of time was spent in review of NASA and LMSC low-cost practice data and data from other sources. The principal data used in these analyses are identified in the "References" of this engineering memo.

A consolidation of the various preliminary lists of low-cost practices was made, with emphasis upon including those which could be the nucleus of action items by NASA. Although some of the practices listed may be in the process of implementation in a specific NASA field center or by efforts of the Low Cost Systems Office in NASA/HQ, they were listed so that a broad scope of practices coverage could be represented.

The LMSC preliminary low-cost practice listing were also reviewed for probable degree of cost impact and several were combined and some omitted from the final listing and data sheets included herein. The cost impact was qualitatively determined as "high", "moderate", or "low". Where the practice impacted certain contractor functional areas more than others, it was so noted on the data sheet. In many cases, the cost impact was rated as applying (essentially equally) to "all areas".

3.8 Use of the Low-Cost Practice Listing

The set of data sheets included herein can be a nucleus set of data which could accompany a NASA-prepared "checklist" of low-cost practices. This checklist could be provided to responsible program/project managers and others in NASA as an initial guide or instruction for implementation. If desired, the use

of such a checklist could be made mandatory, with approvals required by NASA/HQ for any low-cost practice which was not incorporated into the new program (following a pattern similar to that employed in implementing usage of the NASA Standard Components throughout all NASA programs).

4. RISK IMPACT ANALYSIS

4.1 Types of Risk

There have been many publications/documents released on the subject of risk. Most of them deal with business risk, emphasizing the economic aspects of new-business ventures or the actuarial information used by insurance companies. These data are based upon firmly definable variants and/or a collection of historical data on a very large universe of samples over a long period of time. For risk assessment of small-quantity spacecraft programs, each essentially different from the other, the task of specifically identifying risk is much more difficult and intangible.

For the purposes of this analysis, we have taken a qualitative approach in assessment of risk. The general premise applied is that risk characterizes the level of consequences of making a wrong decision/prediction. There appears to be fairly general agreement on the types of risk pertinent to aerospace programs; these have been used in the risk assessment and are in three categories as follows:

a. Performance Risk - This type of risk is the uncertainty that the technical performance and reliability of the operating system will be as predicted or as required. Any increase in the probability that the mission performance will be degraded or that critical failure will occur is classified as an increase in performance risk.

b. Schedule Risk - This type of risk relates to the time interval between the start of the hardware development and the availability of the completed space vehicle (or launch date). Assuming that all major schedule milestones are critical, schedule risk increase is the probability that one or more of the milestones will not be met or more importantly, that the planned launch date will be delayed.

c. Cost Risk - Cost risk is the uncertainty that the actual costs of the program will be different from those estimated. In most cases the negative condition is emphasized, wherein increased cost risk represents a higher probability that there will be a cost overrun on the program.

4.2 Risk for Unmanned Spacecraft With and Without [illegible]

It should be re-emphasized here that the risk assess[illegible] made in this study are pertinent to unmanned spacecraft programs and limited to expendable spacecraft launched by expendable launch vehicles. The scope of the study was limited in this manner to obtain risk impacts of low -cost practices which could be implemented now or in the very near future.

The introduction of the Space Shuttle as the launch vehicle, coupled with its capability to retrieve and/or repair on-orbit those spacecraft which have failed, will lower the program risk for many low-cost practices. Also, use of the Shuttle will allow implementation of additional low-cost practices not included in the listing herein. An example is the potential reduction of spacecraft, subsystem, and component MTBF requirements for those spacecraft which are retrievable by the Shuttle (Note: this practice was omitted from the list presented herein because there appeared to be no cost saving in reducing the operating life or increasing the flight failure probability if an additional spacecraft being launched were the only means to accomplish the mission objective). Conversely, using the Shuttle for retrieval and repair can be shown to less costly than designing the spacecraft for longer lifetime and higher levels of reliability.

As an extension of this initial study, follow-on effort by NASA should be accomplished looking at the additional low-cost practices and/or change in risk impact as a result of using the Shuttle.

4.3 Risk Assessment

4.3.1 The Designator for Change in Risk - The basic risk of implementing each listed low-cost practice has been estimated in a qualitative manner. Broad categories of "increased risk", "no-change", and "decreased risk." were established; each of these represents a delta change in risk when replacing the historical practice with the listed low-cost practice. These designators were applied to each practice separately for each of the risk categories.

Initially, it was planned to estimate the change in risk as high, moderate, or low. Specific considerations of the practices, some of which can be varied in degree of application, forced us to a conclusion that the high/moderate/low sub-classification was not meaningful in the qualitative assessment.

4.3.2 Results of the Risk Assessment - Each low-cost practice was reviewed separately for its impact on risk. Figure 1 is a tabulation of the risk designators applied to each of the practices.

The availability of the "decreased risk" designator proved quite useful. Of the 50 low-cost practices analyzed, 27 were judged to offer decreased risk in one or more of the three risk categories; performance, schedule, and cost.

LCP Number*	Risk**		
	Perf.	Sched.	Cost
1-1	NC	D	D
1-2	NC	NC	NC
1-3	NC	NC	NC
1-4	NC	NC	NC
1-5	D	D	D
1-6	NC	NC	NC
1-7	NC	NC	NC
2-1	D	D	D
2-2	NC	D	D
2-3	D	D	D
2-4	D	D	D
2-5	D	D	D
2-6	D	NC	NC
2-7	I	D	D
2-8	D	D	D
3-1	NC	D	D
3-2	NC	NC	NC
3-3	NC	NC	D
3-4	NC	D	D
3-5	NC	NC	NC
3-6	NC	NC	D
3-7	NC	NC	NC
4-1	NC	NC	NC
4-2	NC	NC	NC

* See list of LCP numbers and titles on pages 4,5.

** "D"= Decrease; "NC"= No Change; "I"= Increase

LCP Number*	Risk**		
	Perf.	Sched.	Cost
5-1	D	D	D
5-2	NC	NC	NC
5-3	NC	D	D
5-4	NC	D	D
5-5	NC	NC	NC
6-1	NC	NC	D
6-2	NC	NC	I
6-3	NC	NC	NC
6-4	NC	NC	D
6-5	NC	NC	NC
6-6	NC	NC	D
6-7	NC	NC	D
6-8	D	D	D
6-9	NC	I	I
7-1	NC	NC	NC
7-2	NC	NC	NC
7-3	NC	D	D
7-4	NC	NC	NC
7-5	NC	NC	NC
9-1	NC	NC	NC
9-2	D	NC	D
9-3	NC	NC	D
9-4	NC	NC	NC
9-5	NC	NC	NC
10-1	NC	D	D
10-2	D	D	D

Figure 1 - Risk Designators Assigned to Low-Cost Practices

A "no-change" designator was assigned for one or more risk categories on 38 of of the 50 practices.

Of large significance is that an "increased risk" classification was placed upon only 3 practices of the 50. This means that almost all of the low-cost practices listed on the 50 Data Sheets can be implemented with no increase in program risk. This was an unexpected result of the risk assessment performed. A partial explanation for the low incidence of increased risk practices may lie in our sifting out some of the lower-cost-driving practices which may have been designated as an increased risk; an example of this is the omission of a practice to lessen the type and amount of reliability analysis - this was omitted because the cost impact on the program was considered comparatively small. Had this practice been included, it would probably been designated as a minor increased risk in the performance category.

4.3.3 Rationale for Risk Classification Assignment - Each of the attached Data Sheets contains an explanation of the rationale or logic used when assigning the risk classification.

The rationale have been made fairly brief, hopefully to assure that it is read by prospective implementors (program managers, etc.) of the low-cost practices. Each rationale statement was separately generated for the specific practice rather than being extracted from a "standard" list of rationale.

5. RESULTS OF PRACTICE IMPLEMENTATION

On each Data Sheet, there is provided an outline of the results of the low-cost practice implementation on a typical program. This information is an extension of the practice description, discussing the principal program impacts in terms of elimination/reduction of work items and reduction of cost in specific areas or functions.

Here again, highlights only of the program impact are defined, hopefully to the degree that the user of the Data Sheet can quickly obtain a feel for the objective of the practice and the extent of the cost reduction without having to read a longer and more general narrative.

1. LMSC-D387517 dated 30 May 1974, "Final Report - Low Cost Program Practices for Future NASA Programs", Contract NAS 8-28960 S/A #5

2. LMSC-D426642 dated 18 June 1975, "Interim Results Presentation - Low Cost Program Practices Study (NAS W-2752)"

3. "Management Study of NASA Acquisition Process - Report of Steering Group", dated June 1971 (Richard McCurdy, Chairman)

4. "AIA Study of Air Force RFP's" dated 9 January 1970, Administrative Memo No. 70-1

5. "DOD's Space Test Program", Lt.Col. Frank a Paparozzi and Capt. Neal T. Anderson, Astronautics and Aeronautics, June 1974

6. "Cost Growth in Major Weapon Systems", Dept. of Defense, by the Comptroller General of the United States, dated 23 March 1973

7. "Recommendations for Develppment of Major Defense Systems and Solutions to Design Complexity and Cost Problems", National Security Industrial Assoc., dated October 1973

8. "Cost Study of Unreasonable Contract Requirements" (Draft), Office of the Asst. Secy. of Defense (Installations and Logistics), Washington D.C., dated 30 November 1973

9. "Lower Space Costs Mean More Space Flight", A.O. Tischler, Astronautics and Aeronautics, June 1974

10. "Management Approach Recommendations", Report No. 4, Earth Observatory Satellite System Definition Study, Contract NAS 5-20520, Grumman Aerospace Corp., Bethpage, N.Y., September 1974

11. "Management Approach Recommendations", Final Report 4, Earth Observatory Satellite System Definition Study, No. 22296-6001-RU-03, TRW Systems Group Redondo Beach, Calif., 1 October 1974

12. "Low-Cost Management Approach and Recommendations", Report No. 4, Earth Observatory Satellite Definition Study, No. 74SD4243, Space Div. of General Electric, Valley Forge, Pa., 15 July 1974

13. "Historical Costs Panel Report to the NASA Space Cost Evaluation Program", Norman Rafel (Chairman), 20 March 1973 (NASA/HQ)

14. "Space Program Payload Costs and Their Possible Reduction", NASA TM X-62223, NASA/OAST, Edgar Van Vleck, Jerry Deerwester, Susan Norman, Larry Alton, January 1973

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE

1. LCP No.: 1-1 2. CATEGORY: RFP's

3. LOW COST PRACTICE: Emphasize Complete Definition of Program Elements in Phase C/D RFP

3.1 Emphasize complete program definition based upon known technology. De-emphasize R&D flexibility in the RFP's for hardware production.

3.2 Based upon very thorough Phase A/B configuration definition and completion of tradeoffs, define all program elements and exactly what hardware is required.

4. RESULT OF IMPLEMENTATION:

4.1 Eliminates costing omissions due to incomplete listing/identification of all program elements.

4.2 Cost reduction by elimination of "add on" changes.

4.3 Historical records indicate cost increases (due to changes) of up to 60% occurred during Phase C; an additional 37% during Phase D. Much of this increase was due to lack of complete program definition and could be eliminated by this practice.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering	H	Testing		Reliability		All Other	M
Manufacturing		Materiel		Qual.Assur.			

6. DELTA RISK (Increase, No Change, Decrease)

Performance No Change Schedule Decrease Cost Decrease

7. RATIONALE FOR RISK ASSESSMENT:

7.1 Establishment and accomplishment of required performance level is independent of the specific time of definition: therefore no impact of practice on performance risk.

7.2 Schedules based upon complete definitions and known technology will require minimal changes, thereby decreasing schedule risk.

7.3 Cost risks will be decreased because more accurate cost estimates can be made when all program elements are completely defined.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE

1. LCP No.: 1-2   2. CATEGORY: RFP's

3. LOW COST PRACTICE: Preliminary Review of RFP by Contractor

3.1 Provide preliminary RFP's to participating contractors for review and comments, particularly in regard to inclusion of low-cost practices; for example, change or reduction to the specification list to allow use of alternate specs/standards for reduced cost.

4. RESULT OF IMPLEMENTATION:

4.1 Improves probability of incorporation of low-cost approaches into a program at earliest possible time.

4.2 Eliminates need for traditional "high cost" full-response proposal; contractor would submit only a "low cost" program proposal in response to low-cost RFP.

4.3 Takes advantage of industry expertise in lower-cost methods and allows NASA pre-evaluation of same.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering	☐	Testing	☐	Reliability	☐	All Areas	H
Manufacturing	☐	Materiel	☐	Qual.Assur.	☐		☐

6. DELTA RISK (Increase, No Change, Decrease)

Performance No Change   Schedule No Change   Cost No Change

7. RATIONALE FOR RISK ASSESSMENT:

7.1 The degree of performance risk varies basically as the level of performance is changed, usually the higher risks being associated with the higher performance requirements. The performance risk will be traded off by NASA/Contractor for each low-cost alternate approach recommended; approaches which increase risk will probably not be proposed nor approved. Therefore the impact of this practice alone will not change risk.

7.2 The same rationale can be applied to the schedule and cost-overrun risks.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE Page 1 of 1

1. LCP No.: 1-3 2. CATEGORY: RFP's

3. LOW COST PRACTICE: Use RFP to Encourage Lower-Cost Responses

3.1 Phase B and Phase C/D RFP's should clearly state:
(a) Low Cost practices are required.
(b) Practices in all areas should be evaluated.
(c) Which areas should receive special attention.

3.2 Also, the RFP should indicate to what extent low-cost responses will be acceptable in the proposal without risk to contractor of being ruled "non-responsive".

3.3 Require contractors to document cost tradeoffs of alternate low-cost practices during Phase B studies, including risk assessment and cost-savings estimates (documenting assumptions and estimating factors).

3.4 Require contractor during Phase C/D proposal to refine/expand results of Phase B low-cost practice studies to meet specific requirements of Phase C/D RFP.

4. RESULT OF IMPLEMENTATION:

4.1 Obtain recommendations for program cost reductions, with risk assessment and cost estimates, which can be implemented in Phase C/D.

4.2 Obtain lower cost responses and estimates from contractors (by eliminating fear of being non-responsive).

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering		Testing		Reliability		All Areas	H
Manufacturing		Materiel		Qual.Assur.			

6. DELTA RISK (Increase, No Change, Decrease)

Performance No Change Schedule No Change Cost No Change

7. RATIONALE FOR RISK ASSESSMENT:

7.1 Program risks are not impacted by this general practice. An individual risk assessment (impacts on performance, schedule, cost overrun) will be required for each low cost approach proposed by the contractor and will be approved or disapproved by NASA.

Note: See LCP No. 1-6 for condition where a response to a baseline requirement is required in addition to an alternate proposal.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE Page 1 of 1

1. LCP No.: 1-4 2. CATEGORY: RFP's

3. LOW COST PRACTICE: Streamline Response Data Required by RFP

3.1 Reduce/eliminate/simplify data required in contractor proposals:

(a) Detailed information not directly related to program.
(b) Detailed data that is non-essential to the source selection process.
(c) Detailed functional plans prior to completion of program definition.

4. RESULT OF IMPLEMENTATION:

4.1 Save contractor bid/proposal money by eliminating preparation of non-essential material.

4.2 Allow contractors more time in a proposal to improve the quality of truely essential data.

4.3 Save time and money during the NASA source selection process and possibly improve selection results.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering	☐	Testing	☐	Reliability	☐	All areas	M
Manufacturing	☐	Materiel	☐	Qual.Assur.	☐		☐

6. DELTA RISK (Increase, No Change, Decrease)

Performance No change Schedule No Change Cost No Change

7. RATIONALE FOR RISK ASSESSMENT:

7.1 Although this practice would reduce costs, it is upstream of the actual program and has no impact on program risks.

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DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE

1. LCP No.: 1-5   2. CATEGORY: RFP's

3. LOW COST PRACTICE: Emphasize Minimum Acceptable Mission/System Performance Requirements in RFP

3.1 Categorize performance requirements as mandatory or desirable in Phase B RFP's:

(a) Mandatory: Minimum capability to perform the mission at all.
(b) Desirable: Higher level capability selected for the particular program.

3.2 Require tradeoff studies of cost and risk versus performance during the Phase B studies with emphasis on using minimum-acceptable requirements.

3.3 NASA, based upon Phase B study results and the cost/risk impacts, select and establish firm set of performance requirements for inclusion in Phase C/D RFP.

4. RESULT OF IMPLEMENTATION:

4.1 If this practice were rigorously and systematically imposed it would provide clearer visibility of the costs for meeting successively more difficult performance levels associated with mandatory versus desirable performance requirements and allow NASA to establish a firm and cost-effective set of performance requirements at a reasonable risk for inclusion in Phase C/D RFP.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering	H	Testing		Reliability		All Other	M
Manufacturing		Materiel		Qual.Assur.			

6. DELTA RISK (Increase, No Change, Decrease)

Performance: Decrease   Schedule: Decrease   Cost: Decrease

7. RATIONALE FOR RISK ASSESSMENT:

7.1 Would decrease performance risks experienced in historical programs by eliminating impossible or near impossible requirements based upon more detailed analysis of what work tasks, state-of-the-art breakthroughs, processes, and costs are necessary to accomplish various levels of performance.

7.2 Having a firmly-fixed set of performance requirements will allow better schedule planning and reduce schedule risk in Phase C/D.

7.3 The tradeoffs to achieve cost-effective performance levels will provide a firmer base for program cost estimates, thereby decreasing cost overrun risk.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE

1. LCP No.: 1-6 2. CATEGORY: RFP's

3. LOW COST PRACTICE: Lower-Cost Alternate Proposals (Lower than Baseline)

3.1 Request in the Phase B and C/D RFP that contractors submit alternate proposal for lower-cost alternate approaches, including altered performance requirements or schedules, which will result in significant cost reductions.

3.2 Require a risk analysis to accompany each Phase C/D proposal, comparing the cost, schedule, and performance risks in complying with the RFP-outlined program versus the contractor-proposed alternatives.

3.3 Establish valid alternate lower-cost approaches as an element of contractor evaluation (source selection).

4. RESULT OF IMPLEMENTATION:

4.1 If implemented, in both phases B and/or C/D, this practice will provide a means of obtaining more contractors' ideas of how to achieve low-costs in programs and detailed evaluation of risks involved. This information can be obtained in two or more iterative steps before a Phase C/D contractor is selected.

4.2 Will exercise industrial innovation and provide the base for implementing lower-cost programs (except for special proprietary methods, if claimed so by the responding contractors).

4.3 If alternate low cost approaches are studied in Phase B, contractor Phase C/D proposal costs will not increase significantly.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering	☐	Testing	☐	Reliability	☐	All areas	H
Manufacturing	☐	Materiel	☐	Qual.Assur.	☐		☐

6. DELTA RISK (Increase, No Change, Decrease)

Performance No change Schedule No change Cost No change

7. RATIONALE FOR RISK ASSESSMENT:

7.1 Although implementation of this practice provides data and estimating factors for comparing cost and risk impacts of both baseline and alternative practices, its overall impact on risk is conservatively judged to be no-change in all three risk categories. This is based upon the belief that low-cost alternatives which are shown to increase risks significantly will not be proposed by contractors normally nor will they be accepted by NASA for most flying hardware.

Note: See LCP No. 1-3 for condition where baseline response is not required and a lower-cost proposal alone is desired.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE

1. LCP No.: 1-7   2. CATEGORY: RFP's

3. LOW COST PRACTICE: Reduce Requirements for Contractor Plans in RFP's

3.1 Do not require the preparation of 15 to 20 contractor plans (Mgt., Eng'g., Mfg, Test QA, Reliability, etc) to be included with each proposal response. (at a time when spacecraft system hardware is not yet completely defined).

3.2 One alternative is to require contractors submit a set of general "standard plans" including relevant contractor internal operating procedures which, if validated by NASA, could be used in lieu of re-preparation of program-peculiar plans for each proposal.

3.3 Another alternative: require only preliminary plan outlines sufficient to justify estimated costs in proposal.

3.4 Require detailed final plans after contractor selection (only one per program).

4. RESULT OF IMPLEMENTATION:

4.1 Validation of contractors' capabilities via a set of standard plans would avoid much of the expenditure now required to have several contractors elaborately develop and document program-peculiar plans at point when definition of program hardware/software items is incomplete.

4.2 Would eliminate consideration of potentially incomplete and/or misleading plans from the contractor-selection process (save source selection costs).

4.3 Could save program costs by eliminating premature startup of the detailed planning cycle.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering		Testing		Reliability		All Areas	M
Manufacturing		Materiel		Qual.Assur.			

6. DELTA RISK (Increase, No Change, Decrease)

Performance No change   Schedule No change   Cost No change

7. RATIONALE FOR RISK ASSESSMENT:

7.1 Delaying preparation of detailed program-peculiar plans until after all program elements are completely defined would not change true program risks.

7.2 Premature (before program definition is complete) documentation of such plans may not uncover true risk factors and therefore be misleading in the source selection and program evaluation processes.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE

1. LCP No.: 2-1 2. CATEGORY: Design

3. LOW COST PRACTICE: Minimum-Cost Design Requirements for Spacecraft and Experiments

3.1 Place a minimum-cost general requirement upon spacecraft and experiments. Specify a mandatory-minimum level of hardware requirements to perform the minimum-required mission.

3.2 Require mission performance/cost tradeoffs to show "choices" of performance levels under lower program cost ceilings.

4. RESULT OF IMPLEMENTATION:

4.1 Will reduce the cost of both spacecraft and experiments; will encourage:

(a) Greater use of proven technologies or equipment.
(b) Use of lower-cost materials/processes.

4.2 Will force consideration of lower-cost methods of analysis and testing.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering	☐	Testing	☐	Reliability	☐	All Areas	H
Manufacturing	☐	Materiel	☐	Qual. Assur.	☐		☐

6. DELTA RISK (Increase, No Change, Decrease)

Performance Decrease Schedule Decrease Cost Decrease

7. RATIONALE FOR RISK ASSESSMENT:

7.1 The easier attainment of lessened performance levels for new equipment will reduce the performance risk.

7.2 The reduced development and qualification testing of lesser-performance equipment (average) will tend to reduce the schedule and cost-overrun risks.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE

1. LCP No.: 2-2 2. CATEGORY: DESIGN

3. LOW COST PRACTICE: NASA Low-Cost Design Handbook

3.1 Prepare and issue a NASA-wide handbook (for use also by co[illegible]actors) for designing low-cost spacecraft and experiments and GSE. Hanubook to cover both expendable-launched and Shuttle-launched/serviced unmanned spacecraft.

3.2 Include all aspects of design which impact Mfg., testing, and operations; emphasizing low-cost materials, methods, processes, standard components, standard spacecraft, refurbishment/reuse of components.

4. RESULT OF IMPLEMENTATION:

4.1 General and widespread implementation of low-cost design techniques within NASA and throughout industry.

4.2 Callout of Handbook in new-program RFP's would insure early adoption and "payoff" in lower hardware/software costs.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering		Testing	H	Reliability		Operations	H
Manufacturing	H	Materiel	H	Qual.Assur.	M		

6. DELTA RISK (Increase, No Change, Decrease)

Performance No change Schedule Decrease Cost Decrease

7. RATIONALE FOR RISK ASSESSMENT:

7.1 Because the incorporation of low-cost design practices are not intended to alter program performance requirements, implementation will result in no change to performance risk.

7.2 As a result of designs requiring less exotic and commercially available standard materials, simplified tooling and testing techniques and similar low-cost approaches; schedule and cost risks will be reduced.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE Page 1 of 1

1. LCP No.: 2-3 2. CATEGORY: DESIGN

3. LOW COST PRACTICE: Use Flight-Proven Hardware in New Spacecraft Design

3.1 Where possible, require use of equipment developed and proven on previous program(s).

3.2 Require minor modifications (where necessary) to existing designs rather than develop new hardware.

(NOTE: Flight-proven hardware may or may not be listed as "available" in the NASA "Catalog of Available and Standard Equipment".

4. RESULT OF IMPLEMENTATION:

4.1 Reduction in engineering costs for new design and analysis.

4.2 Minimum qualification testing; limited primarily to testing of interfaces with other vehicle subsystems, components.

4.3 Reduced documentation required for proven design.

4.4 Mfg. processes already "wrung-out"; lessened QA required.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering	H	Testing	H	Reliability	H		
Manufacturing	M	Materiel	M	Qual.Assur.	H		

6. DELTA RISK (Increase, No Change, Decrease)

Performance Decrease Schedule Decrease Cost Decrease

7. RATIONALE FOR RISK ASSESSMENT:

7.1 Newly-developed equipment always entails some uncertainty in actual performance; use of pre-tested/flown hardware reduces this performance risk.

7.2 Re-procurement of the same hardware presents lesser schedule risks than establishing new mfg/testing procedures on a new-design piece of equipment.

7.3 The actual cost of proven equipment (with updates for inflation, etc.) offers a much firmer base than estimates for new equipment; potential cost overrun risk is reduced.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE

1. LCP No.: 2-4 2. CATEGORY: DESIGN

3. LOW COST PRACTICE: Use of NASA Standard Components (Equipment Items)

3.1 Require the utilization of NASA Standard Components in implementing new spacecraft designs to avoid new development costs.

4. RESULT OF IMPLEMENTATION:

4.1 Reduced design/analysis costs for components for each using program.

4.2 Makes possible a quantity-buy approach which normally reduces the unit cost of components.

4.3 Provides a potential pool of equipment and larger flexibility for priority procurement from selected sources.

4.4 Negates need for component requal test and reduces required level of QA on components.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering	H	Testing	H	Reliability	H		
Manufacturing	H	Materiel	M	Qual.Assur.	H		

6. DELTA RISK (Increase, No Change, Decrease)

Performance Decrease Schedule Decrease Cost Decrease

7. RATIONALE FOR RISK ASSESSMENT:

7.1 Equipment which has been selected as a NASA standard, has already undergone considerable testing and higher confidence of satisfactory operation exists. Performance risk is therefore decreased some from equivalent new program-peculiar component.

7.2 Multi-program usage of a component will assure firmer source(s) for procurement (or from GFE pool), thereby reducing schedule risk.

7.3 With development/qual and initial procurement completed, actual cost histories are available and cost overrun risk is thereby decreased.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE

1. LCP No.: 2-5 2. CATEGORY: DESIGN

3. LOW COST PRACTICE: Lower-Cost Design Requirements for Subcontractor/ Supplier Equipment

3.1 Require that NASA or prime contractors request from suppliers alternate proposals for equipment which will meet the performance/interface design requirements, but can be supplied at lower cost than hardware specified.

3.2 In equipment specs, prescribe widest possible tolerances on inputs/outputs to allow consideration of lower-cost hardware which may operate at other than the nominal but within the allowed tolerance band.

4. RESULT OF IMPLEMENTATION:

4.1 Takes advantage of industrial experience in designing/producing low-cost competitive equipment.

4.2 Incorporation of lower-cost requirements into equipment specifications.

4.3 Utilize available (and proven) industrial designs, mfg. methods.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering	M	Testing		Reliability			
Manufacturing	M	Materiel	H	Qual.Assur.			

6. DELTA RISK (Increase, No Change, Decrease)

Performance Decrease Schedule Decrease Cost Decrease

7. RATIONALE FOR RISK ASSESSMENT:

7.1 Use of existing supplier designs and techniques rather than establishing new equipment spec requirements will reduce the testing and performance risks and improve the probability of on-schedule delivery.

7.2 The use of proven mfg/test technology will also decrease the risk of cost overrun.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE

1. LCP No.: 2-6

2. CATEGORY: DESIGN

3. LOW COST PRACTICE: Higher Design Margins - Less Testing

3.1 Require increased design margins on structure and equipment functional characteristics; affording less-sophisticated analyses and reducing or eliminating structural/functional testing.

4. RESULT OF IMPLEMENTATION:

4.1 Design analyses can be simplified.

4.2 Designs can be verified in many instances by analysis only, without requirement for test verification, or simplified testing can be used.

4.3 Larger functional design margins decreases probability of special stresses or unforecasted failure modes and, in general, lengthens anticipated MTBF.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering	M	Testing	M	Reliability	M		
Manufacturing	L	Materiel	L	Qual.Assur.	L		

6. DELTA RISK (Increase, No Change, Decrease)

Performance Decrease Schedule No Change Cost No Change

7. RATIONALE FOR RISK ASSESSMENT:

7.1 Preflight verification of structural/functional characteristics will be determined using very conservative analyses and, where necessary, simplified over-design-limit testing. Performance risk should thereby be lessened.

7.2 Although minor decreases may occur in schedule and cost overrun risks as a result of testing simplification, a "no change" has been recorded.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE

1. LCP No.: 2-7 2. CATEGORY: DESIGN

3. LOW COST PRACTICE: Lower Level Requirements for Secondary Experiments

3.1 If there are multiple experiments planned for a mission, segregate the primary from the secondary, the latter being those from which degraded (or lack of) data are permissible without jeopardizing the basic mission objectives.

3.2 Limit the application of Reliability, QA, and documentation requirements for these secondary instruments/experiments which are not critical to the prime mission.

4. RESULT OF IMPLEMENTATION:

4.1 The selection of certain mission data as "desirable" but not critical to mission success allows the reduction of reliability/quality and cost on the associated mission-equipment, and certain spacecraft support functions; cost reduction of these equipments will result.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering	☐	Testing	☐	Reliability	☐	All Areas	M
Manufacturing	☐	Materiel	☐	Qual.Assur.	☐		☐

6. DELTA RISK (Increase, No Change, Decrease)

Performance Increase Schedule Decrease Cost Decrease

7. RATIONALE FOR RISK ASSESSMENT:

7.1 There will be a minor increase in overall performance risk because of the potential failure of the secondary experiment(s). However, this will have no impact upon the primary mission accomplishment.

7.2 There will be a small decrease in both schedule risk and cost-overrun risk resulting from the less-stringent requirements applied to the secondary experiment equipment.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE

1. LCP No.: 2-8   2. CATEGORY: DESIGN

3. LOW COST PRACTICE: Standardized and Common Usage GSE

3.1 Standardize selected items of GSE for universal usage among different NASA spacecraft programs: transporters, test sets, servicing carts, etc.

3.2 Re-emphasize use of existing-design GSE as base if it fits the multi-application requirements; re-procure additional items to previous designs rather than redesign requalify.

3.3 Expand application of existing GFE inventory to future programs; utilize NASA "Equipment Visibility System (EVS)" as checklist for callout in RFPS.

4. RESULT OF IMPLEMENTATION:

4.1 Standardization of GSE would also impact spacecraft design, providing the incentive for standard testing and pre-launch operations and standardization of testing software.

4.2 These approaches would interface with spacecraft/experiment standard hardware and provide a minimum overall GSE inventory.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering	☐	Testing	☐	Reliability	☐	All areas	H
Manufacturing	☐	Materiel	☐	Qual.Assur.	☐		☐

6. DELTA RISK (Increase, No Change, Decrease)

Performance Decrease   Schedule Decrease   Cost Decrease

7. RATIONALE FOR RISK ASSESSMENT:

7.1 The standardization of testing GSE and software will result in standard test methods and ability to compare and share test results among programs; collection of test data on a common basis will decrease performance risk on individual programs.

7.2 Use of multi-application or standard-design GSE will allow utilization of pretested or proven equipment, thereby decreasing schedule uncertainties and increasing probability of delivering duplicate equipment to firm cost targets.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE Page 1 of 1

1. LCP No.: 3-1   2. CATEGORY: DOCUMENTATION

3. LOW COST PRACTICE: Use Low-Cost-Driving CDRL's

3.1 Stress a completely finished--not to be exceeded CDRL in each Phase C/D RFP.

(a) Identify each document based on need/worth/cost analysis.
(b) Limit CDRL to minimums in terms of quantity, page count, number of updates, number of copies, etc.
(c) Establish target ceiling cost for total CDRL documentation.

4. RESULT OF IMPLEMENTATION:

4.1 Avoid the practice of having contractors propose excessive CDRL in proposals in response to RFP which is frequently non-specific re: CDRL.

4.2 Use of target cost will emphasize minimum documentation costs to meet realistic minimum documentation needs in future programs.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering		Testing		Reliability		All areas	H
Manufacturing		Materiel		Qual.Assur.			

6. DELTA RISK (Increase, No Change, Decrease)

Performance No Change   Schedule Decrease   Cost Decrease

7. RATIONALE FOR RISK ASSESSMENT:

7.1 True spacecraft performance risks will not be impacted by eliminating excessive documentation typical of traditional programs.

7.2 Schedule and cost risks will both tend to be decreased by the elimination of unnecessary documentation and allowing more concentration of contractor efforts directly on programmatic problems.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE

1. LCP No.: 3-2   2. CATEGORY: DOCUMENTATION

3. LOW COST PRACTICE: Documentation- Need Evaluation Form

3.1 Develop a documentation-need evaluation form for use by NASA in analyzing cost-effectiveness of each document placed on CDRL. Include such information as:

(a) Use intended -- by whom, how frequently.
(b) Content, format page count.
(c) Specific need(s).
(d) Copies, distribution/control intended.
(e) Target cost of document and its maintenance.

4. RESULT OF IMPLEMENTATION:

4.1 Assure that the need and cost effectivenss of each CDRL item has been evaluated prior to RFP release.

4.2 Provides a firm basis for establishing a mandatory-minimum CDRL in accordance with recorded and approved needs.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering	☐	Testing	☐	Reliability	☐	All Areas	M
Manufacturing	☐	Materiel	☐	Qual.Assur.	☐		☐

6. DELTA RISK (Increase, No Change, Decrease)

Performance No change   Schedule No change   Cost No change

7. RATIONALE FOR RISK ASSESSMENT:

7.1 Performance, schedule, and cost risks will not be impacted by realistic documentation need evaluations.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE

1. LCP No.: 3-3 2. CATEGORY: DOCUMENTATION

3. LOW COST PRACTICE: Establish a Central Documentation Function

3.1 Establish a NASA Central (at Hdqtrs. or at Centers) Documentation Control Team.

3.2 Establish minimum-documentation list (with guidelines) for use in future programs; list to be based on cost/need/worth evaluations.

3.3 Monitor RFPs, proposals and programs to assure documentation requirements are minimum and cost-effective.

4. RESULT OF IMPLEMENTATION:

4.1 Change NASA historically high documentation practices based on "desirements" to low cost practices based on cost/need analyses.

4.2 Reduce costs for documentation in future programs.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering		Testing		Reliability		All Areas	M
Manufacturing		Materiel		Qual.Assur.			

6. DELTA RISK (Increase, No Change, Decrease)

Performance No Change Schedule No Change Cost Decrease

7. RATIONALE FOR RISK ASSESSMENT:

7.1 Performance and schedule risks will not be changed by this practice as the vital data relative to these risks will still be documented in minimum form.

7.2 Cost overrun risk will tend to decrease because of the firmer estimates possible on an austere minimum set of documentation.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE

1. LCP No.: 3-4   2. CATEGORY: DOCUMENTATION

3. LOW COST PRACTICE: Use Direct Contact in Lieu of Paperwork

3.1 Establish an operating practice for maintining NASA visibility of contractor efforts by direct contact; use more NASA representatives in contractor plants in lieu of massive documentation requirements and documentation cycles.

4. RESULT OF IMPLEMENTATION:

4.1 Considerable paperwork and documentation update cycles which traditionally have been required to provide NASA visibility of contractor efforts can be eliminated by using more NASA reps in Contractor plants to physically observe contractor efforts, report interim information to NASA via telephone and log sheets, and provide expedited program decisions.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering	☐	Testing	☐	Reliability	☐	All Areas	M
Manufacturing	☐	Materiel	☐	Qual.Assur.	☐		☐

6. DELTA RISK (Increase, No Change, Decrease)

Performance No Change   Schedule Decrease   Cost Decrease

7. RATIONALE FOR RISK ASSESSMENT:

7.1 Spacecraft performance risks will not be impacted by this documenation avoidance practice because the same necessary data will be provided, but in less costly manner.

7.2 Schedule and cost risks will both be reduced via this practice if NASA personnel are assigned responsibility and authority to make decisions with accelerated turn-around time and use of less documentation processing.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE

1. LCP No.: 3-5 2. CATEGORY: DOCUMENTATION

3. LOW COST PRACTICE: Use of Contractor Internal Documentation

3.1 During phase B studies have contractors define the "internal documents" they have generated for similar programs and propose which of these documents could be used in lieu of traditional CDRL items.

3.2 Use contractor internal documentation where possible without conversion to special NASA formats emphasizing use of informal working papers (operating logs, decision logs, fact sheets, computer printout formats (with user instructions)).

4. RESULT OF IMPLEMENTATION:

4.1 Can reduce documentation costs on a program by eliminating the traditional practice of generating two sets of data for the purpose of managing and controlling the same program.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering		Testing		Reliability		All areas	M
Manufacturing		Materiel		Qual. Assur.			

6. DELTA RISK (Increase, No Change, Decrease)

Performance No change Schedule No change Cost No change

7. RATIONALE FOR RISK ASSESSMENT:

7.1 Performance, schedule, and cost risks will not be impacted by eliminating duplicate data generation and transformation of data from one format to another.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE Page 1 of 1

1. LCP No.: 3-6 2. CATEGORY: DOCUMENTATION

3. LOW COST PRACTICE: Lower Cost Engineering Drawings for NASA Unmanned Space Programs

3.1 Implement a low-cost drawing spec which eliminates the need for and use of drawing forms 1 and 2 now required/allowed by MIL-D-1000 and MIL-STD-100A.

3.2 Urge contractors to modify existing contractor drafting manuals which most likely are based on Form 1 and 2 requirements

4. RESULT OF IMPLEMENTATION:

4.1 Lower drawing costs for unmanned space programs having only one to five spacecraft in program by eliminating excessive drawing requirements initially intended for aircraft programs having large production runs.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering	M	Testing		Reliability			
Manufacturing		Materiel		Qual.Assur.	M		

6. DELTA RISK (Increase, No Change, Decrease)

Performance No change Schedule No change Cost Decrease

7. RATIONALE FOR RISK ASSESSMENT:

7.1 Performance and schedule risks will not be impacted by eliminating excessive drawing preparation and drawing control requirements.

7.2 Cost risks will be reduced by avoiding the possibility of getting Form 1 and/or Form 2 practices (because of contractor traditional habits and/or Drafting Practic Manual), and associated costs even when Form 3 is called for in RFP's.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE

1. LCP No.: 3-7 2. CATEGORY: DOCUMENTATION

3. LOW COST PRACTICE: Data Bank to Identify Documentation Costs and Cost Reduction Areas

3.1 Develop a documentation cost data bank to obtain better visibility of estimated and actual costs.

3.2 Distribute data for use by program offices (NASA and Contractor) in cost/worth tradeoffs of new documentation requirements.

3.3 Require contractors to estimate costs (in proposals) and provide actual costs (in program reports) to cover all contractor documents and related costs, including such categories as:

(a) CDRL items
(b) Contractor internal documentation

(continued next page)

4. RESULT OF IMPLEMENTATION:

4.1 Establish a common and credible data base for use in documentation cost/worth tradeoffs in future programs.

Allows reduced documentation costs in future programs by providing dollar base for elimination of unnecessary and/or marginal documents.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering	☐	Testing	☐	Reliability	☐	All Areas	M
Manufacturing	☐	Materiel	☐	Qual.Assur.	☐		☐

6. DELTA RISK (Increase, No Change, Decrease)

Performance No change Schedule No change Cost No change

7. RATIONALE FOR RISK ASSESSMENT:

7.1 Risks will not be impacted by use of credible data in the performance of documentation cost/worth tradeoff evaluations.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE

1. LCP No: 3-7 2. CATEGORY: DOCUMENTATION

3. LOW COST PRACTICE: Data Bank to Identify Documentation Costs and Cost Reduction Areas

3.3 (continued)

(c) Engineering drawings (breakdown by layout, production detail, assembly operation control, etc.)

(d) Plans, Procedures

(e) Test specs and procedures

(f) Management Reports

(g) Technical Reports

(h) WBS Development and Updates

(i) Presentation Charts and supporting documentation

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE

1. LCP No.: 4-1 2. CATEGORY: MANUFACTURING

3. LOW COST PRACTICE: Increased Use of Simplified Tooling

3.1 For small quantity production (less than 25 units) and non-interchangeable items, emphasize use of simple shop aids and reduce need for hard detail and assembly tooling.

3.2 Use hard/controlled tooling for control of major interfaces only where later replacement of hardware item in the factory or in the field is probable.

4. RESULT OF IMPLEMENTATION:

4.1 Use of soft tooling in lieu of hard tooling will reduce tooling costs.

4.2 Surveillance and special control of non-deliverable tooling can be reduced.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering	☐	Testing	☐	Reliability	☐	______	☐
Manufacturing	M	Materiel	☐	Qual.Assur.	☐	______	☐

6. DELTA RISK (Increase, No Change, Decrease)

Performance No change Schedule No change Cost No change

7. RATIONALE FOR RISK ASSESSMENT:

7.1 Use of soft tooling for fabrication and assembly of hardware will not affect the basic configuration nor functional characteristics; performance risk is therefore unchanged.

7.2 Minor decreases in schedule risk and cost-overrun risk may occur, but a no-change category has been assigned.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE

1. LCP No.: 4-2

2. CATEGORY: MANUFACTURING

3. LOW COST PRACTICE: Use of Contractor Proven Manufacturing Processes

3.1 Permit increased use of proven manufacturing processes of contractor or subcontractor rather than impose strict conformance to Government process/control specs.

4. RESULT OF IMPLEMENTATION:

4.1 Use of existing processes, which can be validated by NASA, will eliminate need for preparation of special new documentation and process verification procedures.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering	M	Testing		Reliability			
Manufacturing	M	Materiel		Qual.Assur.	M		

6. DELTA RISK (Increase, No Change, Decrease)

Performance: No Change Schedule: No Change Cost: No Change

7. RATIONALE FOR RISK ASSESSMENT:

7.1 On basis that NASA can review and validate the existing process as adequate, there is no change in impact upon performance, schedule, or cost risk.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE

1. LCP No.: 5-1   2. CATEGORY: PROGRAM DEFINITION AND CHANGES

3. LOW COST PRACTICE: Emphasize Earlier and More Complete Program Definition

3.1 Intensify NASA and Contractor Phase A/B efforts to achieve during Phase B, the scope, level and degree of program definition traditionally achieved after the Phase C/D preliminary design review.

3.2 Require inclusion of NASA program definition/planning lists as part of the Phase B RFP. Require lists to be as complete as possible and in the same format as they will appear in the Phase C/D RFP. Include lists of: (a) design requirements, (b) performance requirements, (c) new technology requirements, (d) technical specs, (e) management and control specs, (f) major hardware/software items (including quantities), (g) lists of government facilities and GSE to be available for the program, (h) Data Requirements List.

(continued on next page)

4. RESULT OF IMPLEMENTATION:

4.1 Will provide much more complete program definition prior to the preparation of Phase C/D RFP and will allow NASA to commit to a much more firmly fixed program in the RFP.

4.2 Can avoid much of the cost growth (approximately 97%) experienced during Phase C/D of some historical programs by eliminating program definition oversights and subsequent "changes" to correct such oversight.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering		Testing		Reliability		All Areas	H
Manufacturing		Materiel		Qual.Assur.			

6. DELTA RISK (Increase, No Change, Decrease)

Performance Decrease   Schedule Decrease   Cost Decrease

7. RATIONALE FOR RISK ASSESSMENT:

7.1 Performance, schedule, and cost risks can all be decreased by postulating a complete and near realistic strawman program definition early in Phase B, firming up the final program definition via tradeoff analysis of all interacting definition variables prior to the end of Phase B.

7.2 Costs and cost risks will also tend to be decreased by allowing more of the "true program" to be costed in Phase B and rechecked/refined during the short Phase C/D proposal response time.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE

1. LCP No: 5-1   2. CATEGORY PROGRAM DEFINITION AND CHANGES

3. LOW COST PRACTICE: Emphasize Earlier and More Complete Program Definition

3.3 Refine and complete the definition/planning lists (as a result of tradeoff studies) during Phase B.

3.4 Encourage selected system, subsystem, and equipment designs to be extended beyond the normal conceptual design level during Phase B when they are necessary to complete the degree of program definition desired.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE Page 1 of 1

1. LCP No.: 5-2 2. CATEGORY: PROGRAM DEFINITION AND CHANGES

3. LOW COST PRACTICE: Program Definition Assessment Check List

3.1 Estab lish and use a Program Definition Assessment Check List (PDACL) to serve as a guide for program managers for including all program elements early in the planning cycle and to assess the degree of program definition completeness during each program phase. This check list should be used in conjunction with the program definition/planning lists described in the LCP No. 5-1.

3.2 Include penetrating questions in the PDACL concerning the status, degree of completeness and degree of firmness of each PD planning list for use in the Phase C/D RFP. Stress need for 100% complete program definition during Phase B.

3.3 If any PD list cannot be completed 100% prior to the end of Phase B, require written justifications of why it can't be and how and when it will be.

4. RESULT OF IMPLEMENTATION:

4.1 This practice will provide a means of assessing program definition development progress and completeness three or more times before a Phase C/D RFP is released.

4.2 Using completed copies of these check/lists to form part of the program historical records will also provide data for post-program comparison of cost versus degree of definition between programs.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering	☐	Testing	☐	Reliability	☐	All Areas	H
Manufacturing	☐	Materiel	☐	Qual.Assur.	☐		☐

6. DELTA RISK (Increase, No Change, Decrease)

Performance No Change Schedule No change Cost No Change

7. RATIONALE FOR RISK ASSESSMENT:

7.1 This practice will not impact program risks directly because the check list is a verification device and is not a requirements document.

7.2 Risk impacts due to better program definition and individual Low Cost Practices proposed to date are reported on separate data sheets.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE Page 1 of 1

1. LCP No.: 5-3 2. CATEGORY: PROGRAM DEFINITION AND CHANGES

3. LOW COST PRACTICE: Establish Minimum Change Policy During Phase C/D

3.1 After thorough and complete program definition in Phase B, establish a minimum change policy for Phase C/D.

3.2 Strive for no changes.

3.3 Reject all cost increasing changes that are not mandatory to meet minimum program objectives/requirements.

3.4 Require thorough analysis of the impact of each change on the total program before approving a change (including the possibility of triggering more changes and total costs for same).

4. RESULT OF IMPLEMENTATION:

4.1 Avoid a program cost growth due to desirable but non-mandatory changes.

4.2 Reduces overall program costs.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering	H	Testing	M	Reliability	L		
Manufacturing	M	Materiel	L	Qual.Assur.	H		

6. DELTA RISK (Increase, No Change, Decrease)

Performance No change Schedule Decrease Cost Decrease

7. RATIONALE FOR RISK ASSESSMENT:

7.1 Performce risk will not be altered because changes required to meet mandatory-minimum performance requirements will still be accomplished.

7.2 Schedule and cost overrun risks will be decreased by eliminating many "improvement only" type changes and the tendency of these changes to "snowball" into a series of schedule delays or cost increases

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE Page 1 of 1

1. LCP No.: 5-4 2. CATEGORY: PROGRAM DEFINITION AND CHANGES

3. LOW COST PRACTICE: Provide Incentives for Minimizing Cost-Increase Changes

3.1 Provide dollar incentives for both NASA and contractors to eliminate cost increasing changes:

(a) Increase contractor fee for all NASA-directed changes which increase program costs.
(b) Decrease or omit fee on all contractor-proposed cost-increasing changes.
(c) Provide cost awards for NASA and contractor personnel who suggest significant cost-decreasing changes during Phase C/D.

4. RESULT OF IMPLEMENTATION:

4.1 Will focus attention on reducing changes and associated costs.

4.2 Will tend to eliminate "modest improvement" changes and cascading of desirable but unnecessary minor changes.

4.3 Will tend to reduce the large program cost growth experienced in Phase C/D of historical programs.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering	H	Testing	M	Reliability	L		
Manufacturing	M	Materiel	L	Qual.Assur.	H		

6. DELTA RISK (Increase, No Change, Decrease)

Performance No change Schedule Decrease Cost Decrease

7. RATIONALE FOR RISK ASSESSMENT:

7.1 Performance risks will not be altered as a result of eliminating changes which are not absolutely necessary to meet minimum performance requirements.

7.2 Schedule and cost overrun risks may be indirectly decreased by reducing the overall number of changes, the possibility for cascades of changes and reducing the unplanned, time consuming rework forced by changes.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE Page 1 of 1

1. LCP No.: 5-5 2. CATEGORY: PROGRAM DEFINITION AND CHANGES

3. LOW COST PRACTICE: Low-Cost Program Practice Check List

3.1 Prepare and distribute a check list of potential low cost program practices for use by NASA Program managers/planners. Provide backup data explaining the result of implementation and the rationale of risk impact (could be a set of data sheets similar to these LCP Risk Impact Data Sheets).

3.2 Require that NASA Program Office and contractor fill out check list designating which practices are being incorporated in a program.

3.3 Require written justification for using a traditional (high-cost) practice when an alternative low cost practice is available.

3.4 Request NASA and contractors to identify additional low cost alternative practices, and evaluate cost and risk impacts, to expand the initial check list during Phase B studies.

4. RESULT OF IMPLEMENTATION:

4.1 Will focus attention on low cost program practices and get wide-spread contribution toward their indentification and use.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering		Testing		Reliability		All areas	H
Manufacturing		Materiel		Qual.Assur.			

6. DELTA RISK (Increase, No Change, Decrease)

Performance No Change Schedule No Change Cost No Change

7. RATIONALE FOR RISK ASSESSMENT:

7.1 This practice will not impact risks directly. Separate risk assessments will have been made or will be required for each individual low-cost practice incorporated.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE Page 1 of 1

1. LCP No.: 6-1 2. CATEGORY: PROGRAM MANAGEMENT (Organization)

3. LOW COST PRACTICE: Low-Cost Oriented Program Staff

3.1 Continue to encourage assignment of Program Managers, both NASA and Contractor, who have strong "low cost" working philosophies as well as technical/management capability.

3.2 Require assignment to Program Staff of a Design-to-Cost, Life Cycle Cost, or Value Engineering Specialist(s) to pursue program cost reduction (and risk assessment) and minimal target cost objectives throughout all phases of the program, particularly during the early phases before designs are frozen.

3.3 Establish a general minimum-cost policy that all program participants must challenge the need for and evaluate carefully any cost-increase elements.

4. RESULT OF IMPLEMENTATION:

4.1 Provide a continuing effort emphasing minimum cost and cost-reduction.

4.2 Increase emphasis on lower-cost at the working level.

4.3 Applies attention to the "people problem" in directing attention to non-traditional aspects of lower-cost programs.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering	☐	Testing	☐	Reliability	☐	All Areas	H
Manufacturing	☐	Materiel	☐	Qual.Assur.	☐		☐

6. DELTA RISK (Increase, No Change, Decrease)

Performance No Change Schedule No Change Cost Decrease

7. RATIONALE FOR RISK ASSESSMENT:

7.1 Most of the low-cost methodology adapted will have no impact on increased performance or schedule risk. Each cost reduction approach will be thoroughly analyzed for impact before implementation.

7.2 The general emphasis placed upon minimum cost will be a strong driver not only to reduce cost but to reduce the probability of program cost overrun.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE Page 1 of 1

1. LCP No.: 6-2 2. CATEGORY: PROGRAM MANAGEMENT (Cost Records/Estimating)

3. LOW COST PRACTICE: New Set of Low Cost CER's (Cost Estimating Relaionships)

3.1 Develop a set of low-cost Cost Estimating Relationships (CERs) to be used in lieu of historical CERs for obtaining very austere target costs for programs.

3.2 Provide new CERs to contractors for reference and use as a base for developing additional low-cost approaches.

3.3 As new cost data accumulates, the low-cost CERs can be "validated" and updated and eventually replace the current and historical "high cost" CERs.

4. RESULT OF IMPLEMENTATION:

4.1 Setting a low target cost will place pressure upon the program to execute at a lower cost than the traditional programs.

4.2 The "average" actual costs from programs using the low-cost CER's will be significantly lower than historical programs although some minor overruns of the low-cost targets may occur.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering	☐	Testing	☐	Reliability	☐	All Areas	H
Manufacturing	☐	Materiel	☐	Qual.Assur.	☐		☐

6. DELTA RISK (Increase, No Change, Decrease)

Performance No Change Schedule No Change Cost Increase

7. RATIONALE FOR RISK ASSESSMENT:

7.1 The use of low-cost CER's has no impact upon hardware performance or program schedule.

7.2 The establishment of austere low-cost targets upon programs may in some cases result in a slightly increased possibility of overrunning the target cost. However, the thorough pre-planning and careful costing required to stay under the initial target, and holding back a contingency fund, will reduce the overrun probability.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE

1. LCP No.: 6-3

2. CATEGORY: PROGRAM MANAGEMENT (Interfaces/Meetings)

3. LOW COST PRACTICE: Small Program Teams and Minimum Interfacing

3.1 Assign a minimum-size NASA team to manage program and interface with contractor(s); reviewing and/or approving contractor program, or contributing analyses, testing, etc.

3.2 If possible, representative(s) of NASA team should be on-site with contractor program office to expedite interface communications and reduce paperwork by substituting personal contact.

3.3 Limit formal technical reviews to system and subsystem level; hold informal reviews at component or black box level. Designate minimum-quantity of NASA and contractor personnel at review meetings.

4. RESULT OF IMPLEMENTATION:

4.1 Reduction in quantity of interface meetings and reduction of specialist reviewing/approving design.

4.2 With reduced formal reviews, contractor documentation and personnel to support the reviews can be reduced.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering	H	Testing		Reliability	H		
Manufacturing		Materiel		Qual.Assur.			

6. DELTA RISK (Increase, No Change, Decrease)

Performance No Change Schedule No Change Cost No Change

7. RATIONALE FOR RISK ASSESSMENT:

7.1 The reduction in customer/contractor interfacing personnel should improve the quality of review and focus attention onto primary areas important to program success and cost.

7.2 Providing for less formal and expedited review of data will tend to improve schedule accomplishment.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE Page 1 of 1

1. LCP No.: 6-4 2. CATEGORY: PROGRAM MANAGEMENT (Cost Records/Estimating)

3. LOW COST PRACTICE: Visibility of Program Practice Cost Impact (Cost Records/Estimates)

3.1 Require a revised contractor cost reporting system which will provide separate labor cost summaries for functional areas such as Systems Engineering, Reliability, QA, etc., against any hardware level down through the component level.

3.2 Provide also for separate cost totaling and tracking of impact of selected cost-driver practices in areas such as Documentation, Testing, Configuration/Data Management, Program Planning/Control.

4. RESULT OF IMPLEMENTATION:

4.1 Identification of costs on a program at various hardwave levels contributed by the various functional organizations, thereby allowing post-analysis of impact of practices such as depth of QA surveillance, engineering time spent on documentation, cost of reliability testing, and similar.

4.2 Cost visibility offered will aid in alteration of methods to reduce cost, focusing on the main cost drivers.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering		Testing		Reliability		All Areas	M
Manufacturing		Materiel		Qual.Assur.			

6. DELTA RISK (Increase, No Change, Decrease)

Performance No Change Schedule No Change Cost Decrease

7. RATIONALE FOR RISK ASSESSMENT:

7.1 Requiring only a change in cost recording, this practice does not have any impact on hardware performance nor on program schedule.

7.2 Identifying the cost contribution of various program practices at various hardware levels will increase the program cost tracking capability and improve cost control and will tend to decrease cost overrun risk.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE

1. LCP No.: 6-5   2. CATEGORY: PROGRAM MANAGEMENT (Planning/Control)

3. LOW COST PRACTICE: Standardized Cost/Schedule Control Systems

3.1 Standarize cost/schedule reporting systems for contractor compliance; use same system for all NASA Centers.

3.2 Make cost/schedule data requirements compatible with data needed by contractor for internal program management; same data to be used by NASA and contractor.

3.3 Eliminate use of 533 forms and need for hand-copying of data summaries thereon.

3.4 Coordinate with DoD to establish single standard system for DoD/NASA.

4. RESULT OF IMPLEMENTATION:

4.1 More complete data available to NASA (copies of computer printouts) in lieu of very general 533 data, without cost increase to contractors.

4.2 Standardized contractor reporting systems will reduce overall contractor costs (primarily overhead costs).

4.3 Improved correlation of data within NASA on different programs (part of new cost data bank).

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering	☐	Testing	☐	Reliability	☐	Program Mgt	M
Manufacturing	☐	Materiel	☐	Qual.Assur.	☐		☐

6. DELTA RISK (Increase, No Change, Decrease)

Performance No Change   Schedule No Change   Cost No Change

7. RATIONALE FOR RISK ASSESSMENT:

7.1 The change in cost/schedule recording and reporting has no influence on performance risk.

7.2 Although there may be some improved visibility to NASA of cost data, the impact on schedule or cost overrun risk is essentially unchanged.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE

1. LCP No.: 6-6 2. CATEGORY: PROGRAM MANAGEMENT (Cost Records/Estimating)

3. LOW COST PRACTICE: Standard WBS and Definitions for Cost Elements

3.1 Establish specific and standard NASA-wide WBS defintions for specific functions and hardware with appropriate breakdowns under each.

3.2 Pre-assigned WBS sub-breakdown with WBS dictionary descriptions are recommended.

4. RESULT OF IMPLEMENTATION:

4.1 Will reduce the cost of contractor preparation of program-peculiar WBS and dictionary.

4.2 Will provide a common-cost-collection system with no question about what cost elements were included or omitted under each titled item of the breakdown.

4.3 Will allow comparison of costs program-to-program and identification of special cost-driver elements.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering	☐	Testing	☐	Reliability	☐	Program Mgt	M
Manufacturing	☐	Materiel	☐	Qual.Assur.	☐		☐

6. DELTA RISK (Increase, No Change, Decrease)

Performance No Change Schedule No Change Cost Decrease

7. RATIONALE FOR RISK ASSESSMENT:

7.1 There is no impact of this practice upon performance and schedule risk.

7.2 The standard cataloging of all program cost elements will provide a better base for collection of cost data, use of which can improve confidence in estimates of later programs, thereby tending to decrease cost overrun risks.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE

1. LCP No.: 6-7

2. CATEGORY: PROGRAM MANGEMENT (Cost Records/Estimating)

3. LOW COST PRACTICE: Common Cost Data Bank (Cost Records)

3.1 Establish a NASA-wide cost data bank which will allow collection/recording of costs down through major component level and with breakouts for direct labor, material, overhead, for both NASA and contractors.

3.2 The bank should record initial estimated costs as well as actual program costs and should contain listings of "normal" or "alternate low-cost" approaches which were on the actual program.

4. RESULT OF IMPLEMENTATION:

4.1 Provide data for cost impact analyses of normal versus low-cost approaches and preparation of low-cost CER's for use on future programs.

4.2 Provide basis for establishment of firm and lower-cost targets for new program Design-to-Cost.

4.3 Allow easier evaluation of contractor cost proposals and easier analysis and monitoring of principal program cost drivers.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering	☐	Testing	☐	Reliability	☐	All Areas	M
Manufacturing	☐	Materiel	☐	Qual.Assur.	☐		☐

6. DELTA RISK (Increase, No Change, Decrease)

Performance No Change Schedule No Change Cost Decrease

7. RATIONALE FOR RISK ASSESSMENT:

7.1 This practice deals principally with cost data; therefore program performance and schedule risk are not impacted.

7.2 Use of the data bank will provide a firm base for estimating of new and follow-on programs and designation of program ground rules impacting cost. This will have a significant effect upon reducing probability of program cost overruns.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE

1. LCP No.: 6-8

2. CATEGORY: PROGRAM MANAGEMENT (Interfaces/Meetings)

3. LOW COST PRACTICE: Experimenter Interface Improvement

3.1 Establish an early and firm technical interface between the Experimenter(s) and spacecraft management teams to assure compatible interfaces with minimum downstream change potential.

3.2 Try for completion of experiment development (coordinated with spacecraft) before start of Phase C/D on spacecraft.

3.3 Require spacecraft contractors review/signoff of experiment interface drawings.

4. RESULT OF IMPLEMENTATION:

4.1 Early interfacing will allow "compromises" on both experiment(s) and spacecraft in arriving at optimized low-cost configurations and hardware.

4.2 Prior proving of experiment in development will solidify spacecraft requirements, thereby leaving minimum program change potential.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering	M	Testing	M	Reliability		Experimenters	M
Manufacturing	M	Materiel		Qual.Assur.			

6. DELTA RISK (Increase, No Change, Decrease)

Performance Decrease Schedule Decrease Cost Decrease

7. RATIONALE FOR RISK ASSESSMENT:

7.1 The performance risk for the combined experiment/spacecraft will be reduced by early compatibility analyses and coordination of functional interfaces, testing, etc.

7.2 Early and continued interfacing will have a strong influence on reducing possible changes to experiment and/or spacecraft, thereby decreasing schedule and cost risk.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE

1. LCP No.: 6-9

2. CATEGORY: PROGRAM MANAGEMENT (Config. Mgt)

3. LOW COST PRACTICE: Reduce Program Hardware Traceability Requirements

3.1 Reduce or eliminate requirements for limited quantity (less than five flight articles) production programs in areas of part and material traceability, identification, material certifications, numbering and codes, etc.) and configuration traceability.

4. RESULT OF IMPLEMENTATION:

4.1 Hardware traceability and associated documentation and costs, intended primarily for larger-quantity, field-replaceable hardware, will be reduced.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering	H	Testing		Reliability	H		
Manufacturing	M	Materiel	M	Qual.Assur.	M		

6. DELTA RISK (Increase, No Change, Decrease)

Performance No change Schedule Increase Cost Increase

7. RATIONALE FOR RISK ASSESSMENT:

7.1 The importance of maintaining detail records of specific configuration, usually down through the parts level, on programs with very few flight articles is questionnable regarding useful statistical information. All hardware units are usually built about the same time and are probably functionally interchangeable. Impact on hardware performance is negligible.

7.2 Because there is a possible small advantage in being able to trace more quickly the cause of ground of flight failure and incorporate changes on remaining hardware, there may be minor potential increased risk to program schedule and cost; the degree of risk should be assessed on each new program.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE

1. LCP No.: 7-1 2. CATEGORY: QUALITY ASSURANCE

3. LOW COST PRACTICE: Rewrite of QA Specification

3.1 Prepare and issue a low-cost revised version of the QA Requirements Spec: NHB 5300.4 (1B) or portion of NHB 5300.4 (ID).

3.2 A reduction of QA surveillance is proposed for the rewrite; however, inspection requirements would remain essentially unchanged.

3.3 Emphasize the need to apply the low-cost approaches at all levels of procurement; prime contractor, subcontractor, and suppliers.

4. RESULT OF IMPLEMENTATION:

4.1 Will clarify the specific functions to be performed by QA as opposed to functions to be performed by other contractor organizations to provide a high-quality product.

4.2 Will reduce cost of QA surveillance on a program.

4.3 Will impact subcontract or supplier costs also (a large percentage of total program costs are frequently allocated there).

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering	☐	Testing	☐	Reliability	☐	________	☐
Manufacturing	☐	Materiel	☐	Qual.Assur.	H	________	☐

6. DELTA RISK (Increase, No Change, Decrease)

Performance No Change Schedule No Change Cost No Change

7. RATIONALE FOR RISK ASSESSMENT:

7.1 Proposed reduction of specific QA functions are not intended to alter the basic inspection,nor the testing surveillance performed on the product which would remain essentially unchanged.

7.2 Although the cost of the QA effort will be reduced, the probability of program cost overrun will also be unchanged.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE

1. LCP No.: 7-2 2. CATEGORY: QUALITY ASSURANCE

3. LOW COST PRACTICE: Use of Contractor Quality Manual - Low-Cost Version

3.1 Request contractor to prepare and submit a "low-cost version of his Quality Manual which features low-cost practices listed here and elsewhere and includes a basic program Quality Plan.

3.2 Validate the new Manual and permit use in subsequent contractor proposals in lieu of submitting a new program-peculiar Quality Plan. Require that program-peculiar changes or deviations be submitted as an addendum to the Low Cost Quality Manual.

4. RESULT OF IMPLEMENTATION:

4.1 Eliminates need to submit a new Quality Plan with each proposal (large degree of redundancy among various plans).

4.2 Use of a low-cost Quality Manual would be a strong forcing function toward reduction of program costs.

4.3 Use of validated contractor Quality Manuals would accelerate implementation of low-cost practices.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering		Testing		Reliability		All Other	M
Manufacturing		Materiel		Qual.Assur.	H.		

6. DELTA RISK (Increase, No Change, Decrease)

Performance No Change Schedule No Change Cost No Change

7. RATIONALE FOR RISK ASSESSMENT:

7.1 Many of the Quality Assurance functions can be reduced without degrading the product quality or performance. Also, each of the elements of a new low-cost Quality Manual would be reviewed carefully by NASA before validation, lowering the probability that any unforeseen program risk would be incorporated. Therefore, no change in program risk will result

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE Page 1 of 1

1. LCP No.: 7-3 2. CATEGORY: QUALITY ASSURANCE

3. LOW COST PRACTICE: Lower-Cost Material Review

3.1 Allow use of working-level personnel (contractor only) in lieu of formal MRB for material review and disposition of all but program-critical hardware. Provide for review of log records by Customer QA rep.

3.2 Delegate total customer "Contracting Officer Approval" to the Governemnt QA Rep (participating in the MRB) to approve all "use as is" or "rework" decision.

3.3 Limit the preparation of non-conforming material reports.

4. RESULT OF IMPLEMENTATION:

4.1 Less paperwork and fewer delays in processing non-conforming hardware.

4.2 Allows concentrating attention of MRB on critical elements of the program.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering	M	Testing		Reliability	M		
Manufacturing		Materiel		Qual.Assur.	H		

6. DELTA RISK (Increase, No Change, Decrease)

Performance No Change Schedule Decrease Cost Decrease

7. RATIONALE FOR RISK ASSESSMENT:

7.1 The informal activity in lieu of formal MRB on non-critical hardware items will not involve increased performance risk because the dispositions are reviewed by the Customer QA Rep and cannot pass unnoticed. Also, non-conforming material reports are "after the fact" documentation and have no influence on corrective action relating to the non-conforming hardware and will therefore not impact performance risk.

7.2 The reduction of delays in processing hardware will tend to decrease schedule and cost overrun risks.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE

1. LCP No.: 7-4

2. CATEGORY: QUALITY ASSURANCE

3. LOW COST PRACTICE: Reduce QA Effort on Previously-Qualified Hardware

3.1 Where previously-qualified and/or flight proven hardware is used, require reduced QA support for surveillance of these items (considerably less than require for newly-developed or first usage equipment).

3.2 Apply also to standard hardware where usage experience has demonstrated product quality.

4. RESULT OF IMPLEMENTATION:

4.1 General simplification of QA surveillance effort, fewer detail inspections required, and general reduction of QA costs.

4.2 With increased use of NASA standard hardware, implementation could result in lower costs at an early date.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering	☐	Testing	☐	Reliability	☐	________	☐
Manufacturing	☐	Materiel	☐	Qual.Assur.	H	________	☐

6. DELTA RISK (Increase, No Change, Decrease)

Performance No Change   Schedule No Change   Cost No Change

7. RATIONALE FOR RISK ASSESSMENT:

7.1 Where adequate qualification and/or satisfactory flight experience has been demonstrated on a hardware item, nothing is gained from further detailed inspection. No change in program risk therefore is forecast for applying the minimum QA surveillance to the "proven" hardware elements.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE Page 1 of 1

1. LCP No.: 7-5 2. CATEGORY: QUALITY ASSURANCE

3. LOW COST PRACTICE: Reduce Quantity of Inspection Points

3.1 Empahsize that inspection of hardware be performed at the highest possible assembly level to reduce the redun of inspections. Inspect at total assembly if all parts are still visible. Require minimum inspection points in the manufacturing process, emphasizing product quality in the completed artic

3.2 equire that critical dimensions requiring inspection be identified on the Engineering drawing; all other dimensions need not be verified by Inspection.

4. RESULT OF IMPLEMENTATION:

4.1 Reduction in the inspection cost of parts and subassemblies when their principal characteristics can be verified in later assemblies or installations.

4.2 Emphasis on critical dimensions only will focus inspection efforts on those areas most important to product quality and intended use of hardware.

4.3 Showing inspection requirements on Engineering drawing will assure early Engineering/Inspection coordination and possibly eliminate need for separate Inspection Instructions.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering	☐	Testing	☐	Reliability	☐	________	☐
Manufacturing	☐	Materiel	☐	Qual.Assur.	M	________	☐

6. DELTA RISK (Increase, No Change, Decrease)

Performance No Change Schedule No Change Cost No Change

7. RATIONALE FOR RISK ASSESSMENT:

7.1 Inspection is often performed on all characteristics of hardware at all levels of assembly, frequently where the elements are not altered during the manufacturing process. Elimination of many of these essentially redundant inspection points and the concentration on critical characteristics only will not alter the program risk.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE

1. LCP No.: 9-1   2. CATEGORY: SPECIFICATIONS

3. LOW COST PRACTICE: Revision or Rewrite of Current Specs to Low-Cost Versions

3.1 Revise existing high-cost driving specs to include only mandatory and lower-cost requirements. Typical examples:

(a) MIL-D-1000 Eng. Drawings Reqts. (c) NHB 5300.4(1B) Quality Assurance
(b) MIL-STD-499 System Eng. Reqts. (d) MIL-STD-883 Testing Requirements

3.2 Establish an altered format for new or revised specs which includes the "rationale" explaining the reasons for the requirements, the cost-driving characteristics, the low-cost objectives, and the altered program risk, if any.

4. RESULT OF IMPLEMENTATION:

4.1 Specifications drive a significant portion of program costs. Selection of the principal cost-driver specs and issuance of low-cost versions of same will have an immediate effect on reduction of new-program costs.

4.2 Inclusion of the "rationale" in the new/revised specs will aid in their quick adoption and implementation of lower-cost methods in NASA and throughout industry.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering		Testing		Reliability		All areas	H
Manufacturing		Materiel		Qual.Assur.			

6. DELTA RISK (Increase, No Change, Decrease)

Performance No Change   Schedule No Change   Cost No Change

7. RATIONALE FOR RISK ASSESSMENT:

7.1 Each low-cost specification before issuance will be preceded by a risk assessment; the increase or decrease in program risk will be explained in the "rationale" portion of the spec. The altered risk, if any, will therefore be known to the cognizant program manager before the spec is applied to a specific program.

7.2 Most of the proposed low-cost changes to specs listed above in 3.1 can be implemented with literally no alternation, or a decrease of program risk.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE   Page 1 of 1

1. LCP No.: 9-2   2. CATEGORY: SPECIFICATIONS

3. LOW COST PRACTICE: Cost-Effectiveness Analysis of Spec Applications

3.1 Require a cost effectiveness analysis to be performed on application of each spec to a program before designating it as a compliance document in RFP.

3.2 Invite contractors to propose deviations to specs or recommend alternate specs either in pre-RFP coordination or in the RFP. Request cost-saving estimates for alternate spec recommendations.

3.3 Also, require preliminary cost-tradeoff analysis of new program-peculiar performance specs prior to issuance of the spec.

4. RESULT OF IMPLEMENTATION:

4.1 Early considerations of the impact of specs on program cost will tend to reduce the types and quantity of specs listed for compliance in the RFP and thereby provide decrease in average contractor cost proposal response.

4.2 Early involvement of contractors in spec "analysis" will prvide additional cost-saving approaches.

4.3 Early performance/cost tradeoffs will focus attention on cost-driver areas of the performance requirements and provide initial potential cost reductions.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering		Testing		Reliability		All Areas	H
Manufacturing		Materiel		Qual.Assur.			

6. DELTA RISK (Increase, No Change, Decrease)

Performance Decrease   Schedule No Change   Cost Decrease

7. RATIONALE FOR RISK ASSESSMENT:

7.1 A preliminary assessment of cost impact for performance specs will probably result in lowering of the performance requirements; this will, on the average, make the performance level more attainable, thereby lowering the risk.

7.2 The focusing of attention on cost-driving characteristics of specs will result in better NASA/contractor cost estimates and a potential decrease in cost overrun risk.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE

1. LCP No.: 9-3   2. CATEGORY: SPECIFICATIONS

3. LOW COST PRACTICE: Do Not Apply General Specs to Contractors

3.1 Re-emphasize elimination or reduction of the application of general specs for Reliability, Safety, Maintainability, QA, Systems Engineering, Human Factors, and similar to a program unless specific paragraphs of these specs are identified (and clarified where necessary to add specificness for compliance in the RFP/contract.

3.2 Require that each segment of each general spec be reviewed prior to inclusion in the RFP to assure that the requirements are mandatory for the specific program.

4. RESULT OF IMPLEMENTATION:

4.1 Full application of these general specs results frequently in over-responsiveness by contractors in applying large numbers of support personnel to a program. Tailoring of the general spec to the specific needs of a program and specifying portions of spec and degree of compliance required will guide contractors to lower-cost responses.

4.2 Reduction in ambiguity of what and how much effort is needed in specific support areas.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering	M	Testing	M	Reliability	H		
Manufacturing		Materiel	H	Qual.Assur.	H		

6. DELTA RISK (Increase, No Change, Decrease)

Performance No Change   Schedule No Change   Cost Decrease

7. RATIONALE FOR RISK ASSESSMENT:

7.1 Clarification of type and degree of spec compliance will allow better cost estimates by NASA/contractor; tendency for cost overruns will be reduced moderately.

7.2 There will usually be no impact upon performance and schedule risk because requirements are being made clearer, not altered. In cases where requirements are reduced, NASA will make the risk assessment at that time.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE

1. LCP No.: 9-4   2. CATEGORY: SPECIFICATIONS

3. LOW COST PRACTICE: Establish Central Spec Control and Coordination

3.1 Establish a central NASA coordinating activity for generation, control, and release of specs for total NASA.

3.2 Emphasize standardization and cost-effectiveness of specs and rewrite of high-cost driver specs to low-cost versions.

3.3 Review newly-proposed specs and spec lists for new programs to assure they are minimum and cost-effective.

4. RESULT OF IMPLEMENTATION:

4.1 Reduce the quantity of different specs applied to contractors.

4.2 Allow contractors to establish low-cost operating procedures to comply with the new cost effective specs.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering	☐	Testing	☐	Reliability	☐	All Areas	H
Manufacturing	☐	Materiel	☐	Qual. Assur.	☐		☐

6. DELTA RISK (Increase, No Change, Decrease)

Performance No Change   Schedule No Change   Cost No Change

7. RATIONALE FOR RISK ASSESSMENT:

7.1 The mandatory elements of specs which impact hardware performance risk or schedule and cost risk would be retained in the new specs. No change in program risk would result.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE

1. LCP No.: 9-5   2. CATEGORY: SPECIFICATIONS

3. LOW COST PRACTICE: Use of a Reduced "Standard" Spec List

3.1 Reduce to a minimum level the quantity and types of NASA and DoD specs in the spec "library" (used as a general reference in selecting specs for inclusion in RFP's as compliance documents).

3.2 Establish a "standard" set of specs and spec list for future NASA programs.

3.3 Reduce or eliminate rewrites of existing specs by NASA Centers into program-peculiar specs where minor changes only are required in the "standard"; state the modification in the RFP/SOW/Contract.

4. RESULT OF IMPLEMENTATION:

4.1 Reduce the average quantity of specs applied to a particular program.

4.2 Eliminate the non-mandatory specs, requirements of which have tended to support some non-mandatory work at contractors.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering	☐	Testing	☐	Reliability	☐	All Areas	M
Manufacturing	☐	Materiel	☐	Qual.Assur.	☐		☐

6. DELTA RISK (Increase, No Change, Decrease)

Performance No Change   Schedule No Change   Cost No Change

7. RATIONALE FOR RISK ASSESSMENT:

7.1 As part of the spec analysis preceding removal of any spec from the "library", the potential impact on typical program risk will be assessed. In general, those mandatory specs which involve risk will be retained in the spec library.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE

1. LCP No.: 10-1 2. CATEGORY: TESTING

3. LOW COST PRACTICE: Optimize Testing for Minimum Cost

3.1 Require tradeoff on each program of which tests shall be performed at component, subsystem, or spacecraft level to obtain minimum overall test cost.

3.2 Require combination where possible of system qualification and acceptance testing using a single proto-flight test article.

3.3 Emphasize high cost of system testing; limit to overall workmanship and end-to-end functional testing. More thorough testing if required should be performed at subassembly, component, and subsystem level. (This approach is made easier by modularizing equipment packaging).

3.4 Emphasize minimum retesting for Standard Components or Standard Subsystem Modules.

4. Result of Implementation

4.1 System tests involve large facilities and large crews of personnel. All possible effort to reduce time of system test and reduce probability of failures occurring (by prior cost-effective testing at lower assembly levels) will result in significant savings.

4.2 Combining qual and acceptance tests will save cost of a test article, but also provide more cost-effective use of test personnel and facilities.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering		Testing	H	Reliability			
Manufacturing		Materiel		Qual.Assur.			

6. DELTA RISK (Increase, No Change, Decrease)

Performance No Change Schedule Decrease Cost Decrease

7. RATIONALE FOR RISK ASSESSMENT:

7.1 A well-planned integrated test program will result from this practice; the limiting of system test to end-to-end functional testing probably will have little impact on flight performance risk if rigorous testing has been done at the subassembly and component level.

7.2 The simplified system test, combined with upstream component/subsystem testing will tend to decrease the probability of schedule slippage or cost overrun risk.

DATA SHEET - RISK IMPACT OF LOW-COST PRACTICE

1. LCP No.: 10-2   2. CATEGORY: TESTING

3. LOW COST PRACTICE: Test Software and Equipment Standardization

3.1 Emphasize standardizing testing equipment and test instrumentation to maximum possible on a single program and among similar programs (minimum quantity of different test equipment modules).

3.2 Require use of commercially-available rather than new program-peculiar test equipment where feasible.

3.3 Require use of the same test software and test equipment (or portions thereof) at component, subsystem, and spacecraft level where possible.

4. RESULT OF IMPLEMENTATION:

4.1 Multiple usage of same piece of test equipment reduces cost.

4.2 Use of standard equipment allows standardization of spacecraft hardware interfaces.

4.3 Use of same test method/test equipment at various levels of assembly increases total test data available for statistical reliability analysis of specific spacecraft hardware elements and increases confidence level in test results.

4.4 Use of proven commerical test equipment lowers development costs.

5. AREA AFFECTED & DEGREE OF COST IMPACT: (High, Moderate, Low)

Engineering		Testing	H	Reliability			
Manufacturing		Materiel		Qual.Assur.			

6. DELTA RISK (Increase, No Change, Decrease)

Performance Decrease   Schedule Decrease   Cost Decrease

7. RATIONALE FOR RISK ASSESSMENT:

7.1 Use of same test equipment and software on multiple units of the same hardware elements increases the confidence level of the test results; provides more data points for same piece of hardware. This will tend to reduce the hardware performance risk.

7.2 Use of standardized test equipment, proven on a previous program will eliminate some "first usage" problems and tend to decrease the schedule and cost overrun risks due to testing.

ENGINEERING MEMORANDUM

TITLE: MIL-STD-810B & MIL-STD-883A, CRITICAL REVIEW AND COMMENTARY.	EM NO: LCPP-16 REF: DATE: September 30/1975
AUTHORS: H K Burbridge.	APPROVAL: ENGINEERING SYSTEM ENGRG [signature]

1.0 General Background: MIL-STD-810B, Environmental Test Methods superseded the original'A'version of the specification in June 1967. Since that time numerous additions have been made to the document, the most recent being issued as a series of new pages to be incorporated, date September 20/1970. Originally intended as a standard series of methods for the environmental testing of aircraft, the document has undergone amendments to transform it into a standard suitable for spacecraft use. The results of such a process will be discussed in this EM as part of the text. MIL-STD-883A, Test Methods & Procedures for Microelectronics; date November 15/1974 overlaps MIL-STD-810B, because it specifies the environments to be considered when applying test to determine the merit of micro-electronic devices, including Integrated circuits (ICs). This document is highly detailed, current, and technically explicit in the methods and conditions it imposes. The MIL-STD does not cover hybridized circuitry, but is in wide use throughout the micro-electronics industry. It will be discussed extensively in the ensuing text.

1.1. Applicability of the Documents: In the broadest sense, MIL-STD-810B sets forth standards for environmental testing at all hardware levels from piece-parts to complete vehicles. Many of the requirements do not apply to spacecraft, either manned, or unmanned, and the requirements which do apply tend to be dated, and require revision. MIL-STD-883A has an impressive sub-tier of other specifications and standards associated with it, many of which would appear to be un-necessary. The subtier will be treated in this EM, in terms of its applicability and pertinence to not only the MIL-STD, but also to unmanned space programs generally.

1.3. Cost Aspects of the MIL-STDS: EM LCPP-3 in this series of Engineering Memoranda showed the influence of both MIL-STDs upon two programs; MVM-73 and the Atmosphere Explorer. Both of these programs undertook an elaborate series of environmental tests on items of hardware from "black-box" up through the assembled flight-ready vehicle; and both programs employed electronic devices containing a heavy complement of micro-electronic elements. From programmatic cost data available from these programs the inference was made that program costs were driven from 3-4% TPC by MIL-STD-810B, and from 7.5-8.0% by MIL-STD-883. (No 'A' version had been issued at the time the programs were undertaken). It was inferred also that program savings of

1.5-2.5% of program costs might be saved by modification of the requirements of both MIL-STDs, and a combination of them into one overall document where possible.

1.4. Analysis Objective: The major objective of this analysis of the two MIL-Stds was to examine the validity of this cost-savings hypothesis, and confirm, or deny its validity.

2.0. Detailed Analysis MIL-STD-810B: This MIL-STD is one of the better examples of a specification which "Grew like Topsy". Originally issued in June 1964 as an 'A' version, the 'B' version was issued in June 1967. Prior to the 'A' version released in 1964, the first version MIL-STD-810 was first invoked in 1952, during the Korean war. The standard was totall aircraft oriented in its application, and served its purpose for a limited time. As high performance supersonic, all-weather, all climates pursuit aircraft became widely used by the US armed services in the middle, and late 1950's; the environmental standard no longer sufficed. Additional criteria wer added, until in 1964 a formal re-issue took place. Realizing the the environmental test methods and criteria were not suitable, not applicable, or both, for spacecraft, yet another issue was made in June 1967, which included chapters on Space Simulation, and Acoustical vibration. Again, the issue was made by the US armed services, and again the issue did not suffice for long. As better understanding of environmental impingement on space hardware became current throughout the aerospace industry, a'B' version was issued in October 1969. During the period of US involvement in the Viet Nam war, new rapid-fire, multi-barrelled armament was added to military aircraft. Other new armament included large caliber fast-fire weaponry (fire rate: fast fire is any delivery rate up to 1500 rounds per minute; vs rapid-fire which is any delivery rate from 1500-7000 and above rounds per minute). These novel weapons imparted severe vibration to aircraft structures, and such vibrations were suspected to contribute materially to structural fatigue. Thus in September 1970 amendments were issued for incorporation into MIL STD 810B, which dealt with methods of simulating the affects of armament vibration on not only structures, but also sensitive equipment mounted to such structures. Minor changes continued to be issued on this subject, the last being October 20 1970. The STD, as of Feb 1975, contains all these amendments.

2.1. Applicability of the STD: As has been so often the case, NASA was "force-fitted"with MIL-STD-810, 810A, 810B, and all amendments issued to date. Most of the material included in the STD does not apply to spacecraft, as stated prev-

iously, so for purposes of reference the STD is compiled as follows:

Sections 1 thru 5 furnish data concerning test methods, referenced documents, test conditions, particulars of test facilities, test sequences, records, and other information pertinent to the overall conduct of tests in compliance with the standard. Methods are given commencing with #500, and continuing thru #512. Methods #513 thru 519 are furnished but these have a subscript numeric .1 to signify that the content of these methods sections have been amended from their original state. The numbers and titles are:

500	Altitude	Aircraft Oriented.
501	High Temperature	Aircraft Equipment Oriented
502	Low Temperature	Aircraft Equipment Oriented
503	Temperature Shock	Aircraft Equipment Oriented
504	Temperature - Altitude	Aircraft Electronic Equipment
505	Sunshine	Equipment Earth's Atmosphere
506	Rain	Equipment Exposure to Rain
507	Humidity	Equipment in Humid Atmosphere
508	Fungus	Equipment in Fungus promoting Atmospheric Environment.
509	Salt Fog	Salt Fog.
510	Dust Test	Equip't in Dust/Sand Envr'mt
511	Explosive Atmosphere	Equip't operation in Explosive Atmos.
513.1	Acceleration	Aircraft/Aircraft Equip Oriented
514.1	Vibration	Aircraft, Air-Air Missiles
515.1	Acoustical Noise	Aircraft, Missiles, Spacecraft
516.1	Shock	Aircraft, Missiles, Spacecraft
517.1	Space Simulation	Spacecraft, Spacecraft Equip'mt
518.1	Temperature - Humidity - Altitude	Aircraft, Aircraft Equip't..
519.1	Gunfire Vibration, Armament.	Aircraft, Aircraft Equip't.

In addition to all of the above, there is method 512 which deals with leakage. The two methods specified are water, and hot oil immersion. The methods seek to determine whether or not a sealed container leaks when submerged in fluid, and the integrity of hermet seals, gaskets, etc. The test method was excluded from the major listing above, as at present it is under scrutiny, and may be deleted from the STD, with another leakage test method being included in its place.

As may be seen from the above listing, only three test methods apply to space-vehicles directly, yet it is common practice for NASA RFPs to invoke the STD routinely, without mention of the specific method sections of pertinence. These three methods are responsible for much of the costs associated with environmental testing of spacecraft, and spacecraft flight hardware; and of the three, the largest cost contributor is method 517.1 Space Simulation.

2.1.1. Specifics of 517.1 Space Simulation: This test method is described as intended for the evaluation of space vehicle components, space vehicle subsystems, and complete space vehicles including installed equipment. The method sets forth in considerable detail seven (7) procedures by which such an evaluation, or set of evaluations, shall be made. The 7 procedures are as follows:

I. Radiant Heat Transfer effect of space, simulated solar spectrum.
II. Cold Absorbing Nature of space, infrared heat source.
III. Cold Surfaces of chamber as source of calculated temperature impression upon test object.
IV. Orbital skin temperature, by infrared heat source.
V. Heat Transfer simulation for components, by use of a conductive, temperature controlled surface.
VI. Simulation of the pressure effects of space, by low pressure chamber
VII. Heat transfer by use of a cryogenic heat sink plus vehicle heaters.

To qualify the terms of these procedures and furnish essential test information, chamber pressures are given for the 7 methods, tabulations of solar energy in space, radiation characteristic of the planets in the solar system, solar simulator classification tabulations, a tabulation of solar electro-magnetic distribution of energy, details of a heat flux simulator, a radiant heat sink, details of test equipment set up, and operating procedures for conducting the tests. Definition of the terms and nomenclature associated with space simulation tests, and thermal-vaccum chambers used for these tests is also provided.
As such, the method is well documented, well written, well ordered as to subject matter, and highly precise in terms of the requirements spectra set forth.

2.1.2. Costs of the Method: The method of space simulation described was first released in 1969 (Oct 20). At that time little was known of the long term affects of a space environment upon sophisticated space hardware, especially at the complete vehicle level. Also at that time, no expense was spared to bring to a close the successful series of lunar missions. Costs were considered secondary to the success of a mission, especially in the Apollo series involving as they did human life.

To give some indication of the costs of space simulation testing the following data are of value:

1. Costs to procure a space simulation facility similar to Chamber "A" at JSFC.
   - o Chamber structure & installation of 60' dia x 65' high unit.$13.5m
   - o Vehicle preparation and assy building......................$ 1.75m
   - o Chamber support equipment (tank farm for gases/consumables).$ 0.75m
   - o Automatic Check-out Equipment (per set)...................$12.00m

   Total $28.00m

The dollar totals are in 1975 dollars, today the costs would be almost double.

2. Operating costs per hour, full scale tests, large vehicle... $1500.00
3. Costs to install LMSC facility approx 1/2 size of JSFC chamber $11.00m
4. Cost to operate $850 per hour.
5. Costs to operate a small chamber such as chamber G at JSFC $275.00/hr. Chamber is approx 7' dia by 10' ht, initial cost $3.74m. (1965 $s)

As a general rule, full scale vehicle tests are run on a 24 hour per day per unit chamber. This requires 3 labor shifts of approx 70 persons per shift, and the hourly rate of expenditure is $1500 per hour as stated. These figures are merely those costs of running the test which for a test such as the service module and the LEM ran for 30 days, at a cost of over 1 million. Test planning test preparation, and site activation cost at least 25 million more when the test teams at the contractor's facility and the test personnel at NASA are considered. LMSC does not suggest that these dollar figures are excessive in a 20+ billion dollar program, especially when the outcomes of the tests conducted afforded the confidence to proceed with the manned program. The sums involved are very costly indeed for a program not requiring such sopjistication, is the point at issue.

2.1.3. Space Simulation Testing, Needed or Not? Currently there is a considerable controversy surrounding whether or not space simulation testing is any longer necessary, particularly in the light of the NASA trend toward the use of standardized flight qualified space hardware. This controversy involves the level of hardware at which such testing is to do undertaken; the determinimg factors being the relative costs at the component and the higher-order levels. One school of thought contends that it makes little sense to test at the complete vehicle level when vehicles involved are relatively small, and unmanned. This appears to be the dominant thinking when cost reduction is considered vital to the success of NASA programs.

Another school of thought, diametrically opposed to the first, contends that the costs of full scale vehicle testing are money well spent, if concealed defects are revealed by the process, especially where the vehicle involved is "one only to be built". The prevailing opinion would appear to be the first, with the generally expressed opinion: "Space Simulation testing is too costly to conduct at the vehicle level, do it at the component level, and only do it for those components which are new and not flight qualified" being heard most frequently.

2.1.3.1. RFP Specifics: LMSC recommends that the RFP be used as the vehicle for resolving the question of level at which to undertake this costly form of testing. Not only must the MIL-STD-810B be invoked for details of the method, but the level must be specified, and any exclusions to the 7 procedures for test set forth in the MIL-STD must be stated. Of those 7 procedures, some are either/or choices; and in these cases, the one required should be identified. If this practice is followed, considerable costs can be avoided. Contractors who have incurred the expense of installing large scale space simulation test facilities, tend to be proponents of their use, for the obvious reason of cost recovery, and installation expense amortization. Similarly, NASA personnel who have been involved with the design, procurement, operation, and maintenance of such facilities tend to favor perpetuation of such facilities. To some degree, NASA facilities for space simulation are necessary, as contractors not possessing such facilities can, and do make use of the NASA test complexes. There is no simple answer to whether or not space simulation testing should be used; but it would appear obvious that the subject should be carefully considered in the light of the cost/worth aspects of such testing prior to its implementation. Above all, specify in the RFP exactly what is believed necessary, and invoke precise section and methods of the MIL-STD rather than invoking it as a "blanket" program standard.

2.1.4. Potential Cost Savings Summary: To illustrate the cost savings possible if space simulation testing is either reduced to the compoent level or eliminated the following tabulated estimates are presented for two programs MVM-73 & A.E.

	Total Test Costs %TPC.	Total Env Test Costs	Total Space Sim.	△
MVM-73	18.0% TPC	3.8%TPC	1.7% TPC	2.1%
A.E.	16.2% TPC	4.0%TPC	1.9% TPC	2.1%

As can be seen from the estimated savings tabulated, on a program costing approx 100 million such as the MVM-73, a potential savings of 2 million is an appreciable amount. Recognition of this fact has caused NASA to modify requirements for both the LST program, and the JPL program Seasat. (JPL is considered as though it were a NASA agency for purposes of this study). On these programs space simulation testing has been required at the component level only, and MSFC and JPL environmental test specifications have been invoked rather than the general MIL-STD-810B.

2.2. General Recommendation: LMSC recommends that NASA no longer invoke MIL-STD-810B except as a reference/guide. NASA should standardize from among the existing environmental test methods/specifications extant at MSFC, JSC, and GSFC, an environmental test methods specification suitable for the forthcoming, standard components era. This Test Standard for NASA use, should include Space Simulation testing at the component level only, and only that, when components to be used are of novel, not flight-proved designs. In cases where space simulation appears essential at the vehicle level, detailed cost trade studies should be made, before undertaking the vehicle level tests. Such studies will confirm or deny the cost effectiveness of tests at the vehicle level.

When MIL-STD-810B is no longer invoked, or invoked only as a reference and guide, other specifications/standards called out by the standard are also negated as the dependency sub-tier. These are:

- o MIL-S-901. Shock Tests, High Impact, Shipboard Machinery, Equipment & Systems, Requirements for.
- o MIL-E-2036. Enclosure for Electric, and Electronic Equipment, Naval Shipboard.
- o MIL-G-5572. Gasoline, Aviation Grades 80/87, 100/130, 115/145.
- o MIL-C-9435. Chamber, Explosion-proof Testing.
- o MIL-C-45662. Calibration of Standards. (also called in NHB 5300.4(1B))

As may be seen, almost all of the above documents do not apply to NASA operational hardware in any manner.

3.0 Detailed Analysis MIL-STD-883A: This MIL-STD-establishes in-depth uniform methods and procedures for testing microelectronic devices, including basic enviromental tests to determine resistance to deleterious effects of natural elements and conditions surrounding military and space operations, and physical and electrical tests. By definition contained within the STD, the term "device" includes such items as monolithic, multi-chip, film, and hybrid microcircuits,

microcircuit arrays, and the elements from which the arrays are formed.
The standard has three purposes:

1. The specification of suitable conditions obtainable in the laboratory, which give test results equivalent to actual service conditions existing in the field, and the assurance of reproducibility of the results of the tests.
2. To describe all of the test methods of a similar character in current use by the joint services and NASA which appear in the various specifications issued by those agencies, in one standard. The object of such combination is the uniformity of test methods and the conservation of test equipment and facilities, as well as manhours.
3. To provide a series of test methods applicable to devices not covered by approved Military/NASA specifications, standards, and/or drawings.

As is usual with MIL-STDs a documents sub-tier of dependencies is included, and these documents may be listed as follows:

Specifications:

Federal: QQS-571 ... Solder, Tin alloy; tin lead alloy; and lead alloy.

MILITARY -

MIL-F-14256 - Flux soldering, Liquid (Rosin base)
MIL-S-19500E - Semi conductor devices; general specification for
MIL-M-38510 - Microcircuits; general specification for
MIL C 45662 - Calibration System Requirements.

STANDARDS

MIL-STD-280- Definition of Terms for Equipment Divisions
MIL-STD-781 - Reliability Tests, Exponential Distribution
MIL-STD-1313 - Microelectronics Terms & Definitions.

In total, all of these documents combined give the impressive figure of 550 printed pages of material which must be read, understood, and applied. In addition to all of the above verbiage contained in these documents, NASA imposes yet another requirement, primarily upon the manufacturers of the microelectronic devices. This document is NHB 5300.4(3C) and is called Line Certification Requirements for Microcircuits. In essence, the document informs the manufacturer that if he wishes to sell his product to NASA, he must process it in the manner prescribed, and inspect it per the criteria set forth in the publication.

As a document, this segment of the NHB series is highly detailed, of sound technical content, and covers every major facet of the manufacturing processes in current use by the semiconductor/microcircuit industry. NASA was obliged to produce such a document (issued in May 1971) since the yield of devices from the production process was low, the process was expensive and non-uniform, supplier to supplier, and the incidence of hidden defectives within the process output was high. The Handbook segment is divided into 4 major chapters, and while it is not invoked or referenced by MIL-STD-883A the following detail is furnished to provide a digest of its contents and pertinence to microcircuit production and acceptance:

Chapter 1. Introduction. Deals with Scope, Applicability, Required Documentation for Line Certification, Applicable Documents invoked, and Definitions of Microcircuitry Terms.

Chapter 2. General Requirements for Line Certification: Cites Pre-requisites for line certification, Phases of Line Certification, Loss of Line Certification (criteria for), Re-instatement of Line Certification, Groups of Circuits to be Manufactured on Certified Line, Levels of Control, Test Options, Fabrication Documents, Location of Process Steps, Environmental Control of Test Areas, Handling of Sub-strates, Water Control, Purity of Materials (criteria for) Corrective Action, and Facility Usage.

Chapter 3. Detail Requirements for Line Certification of Monolithic Micro-Circuits: This chapter deals with: Substrate Characterization, Surface Passivation, Patterning, Junction Forming, Metallization, Metallized Substrate Acceptance (Level II), Scribing and Dicing, Die Sort Inspection, Die Mounting, Interconnect Bonding, Pre-Seal Visual Inspection, and Sealing.

Chapter 4. Guidelines for Maintenance of Line Certification for Monolithic Microcircuits: This chapter is a series of what purport to be guidelines, but since almost all of them commence with the phrase "The contractor shall", in effect, they are mandates. Covered are the requisites for maintaining certifications of the processes of: Substrate Characterization, Surface Passivation, Patterning, Junction Formation, Metallization, Metallized Substrate Acceptance (Level II), Scribing and Dicing, Die Sort Inspection, Die Mounting, Interconnect Bonding, Pre-Seal Visual Inspection, and Sealing.

The Handbook segment includes also a Documents Requirements List (DRL). Review of the document, and knowledge of the subject matter as a whole permits LMSC to state that the requirements are rigorous, the checks and balances are elaborate, and technically complex; the documentation of each of the processes is detailed and exhaustive, and the processes themselves represent the latest state-of-the-art. As such the Handbook segment is largely responsible for the highly reliable microcircuits routinely deliverable to NASA by the industry. The multiple checks and inspections both of process viability and merit, and quality of the end item, are essential to produce the quality level required. However, the entire process of obtaining, and maintaining, line certification is highly costly, and these costs are reflected in the unit cost of the end-item. Whether or not the costs are justified in the light of the possible risk of major mortality occurring in NASA programs, is a moot point. To date, so far as is known no study has been made of the comparative risk associated with each production step on a basis of "Include a specific control", "Exclude a specific control" NASA has been of the opinion that the costs, no matter how great, were money well spent. In the climate of modern austerity which besets the aero-space industry, LMSC believes that <u>such a study would be of benefit, and recommends that one be undertaken.</u> LMSC conducted a cost comparison for micro-circuits, commercial versions vs NASA/Military requirements which show the costs of the specialized units to be 15-20 times that of the commercial units; and it is this type of result (furnished to NASA in a PER Handbook LMSC-D387518, 30 May 1974) which gives rise to the LMSC recommendation.

3.1. <u>Analysis of Dependency Documents</u>: As listed in paragraph 3.0, there is a documentation sub-tier associated with the MIL-STD. The first of these documents stipulates the details of solders intended for use with semi-conductors and microcircuits. MIL-F-14256 similarly, furnishes details of rosin based liquid fluxes recommended for use with these solders. To some degree both the Federal document, and the MIL specification overlap in their intent, as the solder STD covers solders with rosin flux cores. Both these documents are clear, concise, and technically satisfactory, in that they set forth the requirements for metallurgical configurations, chemical constituents, tests to be performed to verify these criteria have been met, and quality assurance and inspection provisions.

The next document in the dependency listing is MIL-S-19500E, Semi-conductor Devices, General Specification for. At first glance the reason for inclusion of this document is not immediately apparent. Further investigation reveals that since MIL-STD-883A purports to cover hybrid circuits as well as micro-circuits, the MIL-SPEC is essential to cover characteristics and requirements of the transistor type of semi-conductor. MIL-S-19500 is yet another specific-ation whose growth has been random. The specification was first released in 1957. Versions A,B, & C followed in the period 1958-1963, with the D version issued in 1964. At that point there was a lull in the amendment process, until the E version plus Supplement 1F was issued in August 1972. Amendment 4 followed in March 1973, and also at that time Appendices A & B were revised to cover Definitions, and Abbreviations and Symbology. In effect, what transpired was that as the technology of discrete semi-conductor devices was developed and refined, so the MIL-Spec was amended/revised to encompass the rapidly changing technology. The trail through the several amendments, supplements, and append-ices can only be described as tortuous. The original specification which deals not only with transistors, but also with diodes covers all the technical para-meters, and some of the detailed requirements for manufacture to military re-quirements. The ubject matter thus ranges from color coding standards for diodes, to internation-agreements concerning standardization. The international agree-ments would appeal to consist of notifying all participants in the agreements when any proposed revision of any kind would violate the agreements aforemenioned. Elaborate and detailed Quality Assurance and Inspection criteria are included in Appendix C, which covers among other matters the criteria for Lot Tolerance Percentage Defective (LTPD) and a sampling table for given sampling plans. Also featured are Life Test, Screening and Burn-in, and Qualification procedures. Throughout the entire publication, there is a requirement for numerous and var-ied reports and documents to be submitted to the military; each evidencing some portion of the overall compliance with the criteria of the specification. In addition to all of the foregoing content, there is the Supplement 1F. This document of 22 pages lists a difference alpha-numeric "slash" designator for individual device types, and generic families of related device types. Examples are MIL-S-19500/1A, a transistor 2N220, to MIL-S-19500/487 (USAF) covering transistors 2N5838, 2N5839, 2N5840, and Jan-TX types of the same genus. Inter-spersed in this listing are diodes MIL-S-19500/124E covers the diodic family TX1N2846B through TX1N2896RB, inclusive of their non TX originals.

Not to belabor the point "ad nauseam", this listing is an attempt to document the detail specification sheet associated with each type, or family of types. The designator Jan signifies a device which has met the specified requirements of the Government procurement agency, and the TX designator very loosely defined, signifies High-Reliability criteria have been met. To the semi-conductor specialist, all of this proliferation of documentation is familiar, but to the average design engineer, it is bewildering in the extreme. As can be seen from the issue date of the latest version, the document is only two years old. However, to make it a useful tool, it needs re-issue as a completely new document, merely to permit progression through its requirements, without any changes to the basic requirements themselves. The electronics designer, contemplating inclusion of a hybridized circuit in his component design, must not only search all the data sheets for the transistor type he wishes to use as a discrete element of the hybrid circuit, but also he must search MIL-M-38510A for a suitable microcircuit to associate with the discrete transistor, PNPN Triode, Thyristor, or SCR (Silicon Controlled Rectifier) device).

3.1.2. MIL-M-38510A, Military Specification, Microcircuits, General Specification for: This specification is another example of documentation proliferation, which has arisen from the attempt to keep software abreast of the development of mircrocircuit technology. As with the 19500 series for discrete devices, this specification for microcircuits contains a supplement 1E which lists by device type, and family, the detail specification sheets for alpha-numeric "slash" designators 1B thru 201. A further sublisting cross-references the military types to similar commercial types. This supplement is dated 14 Feb.1975. Amendment 2 to the specification, dated 10 July 1974, deals exclusively with deletions and substitutions to the basic specification in terms of metallurgy percentages required, and also treats lead finishes, case outlines, flat pack configurations, outlines & dimensions, etc. etc.

3.1.2.1. MIL-M-38510A Main Specification: The main document, issued 3 July 1972, states that the specification establishes the general requirements for monolithic, multi-chip, and hybrid microcircuits, and the quality and reliability assurance requirements which must be met in procurement of microcircuits. This specification has its own sub-tier of documents invoked which includes:

MIL SPECS: MIL-M-55565 Microcircuits, packaging of
MIL-C-45662 Calibration System Requirements.

MIL STDS: MIL-STD-100A Engineering Drawing Practices.

MIL-STD-129 Marking for Shipment & Storage
MIL-STD-883 Test Methods & Procedures for Microelectronics. *
MIL-STD-1313 Microelectronic Terms & Definitions *
MIL-STD-1331 Parameters to be Controlled for the Specification of Microcircuits *

Publications:

FEDERAL: Cataloging Handbook H4-1 Federal Supply Code for Manuf'rs
MILITARY: NAVSHIPS 0967-190-4010. Mfrs Designating Symbols.
NASA: NHB 5300.4(3C) Line Certification for Microcircuits.*

Those documents segregated with an asterisk * are cross referenced in the MIL-STD-883 under discussion, and of particular interest is the NHB 5300.4(3C) which has been discussed earlier in this review.

In reading the document, the user is given information on the entire manufacturing process for microcircuits, and subjects such as device qualification, line certification, design documentation, die topography, device marking, lead metallurgy, bonding, and P.A. requirements. In this latter subject, Product Assurance is specified as to levels and intent in a complete Appendix. This Appendix A is titled Product Assurance program, and it cites an elaborate program of checks and balances for all phases of device production. In addition to the program, Appendix B is furnished which details Statistical Sampling, Test & Inspection Procedures, including the Lot Tolerance Percentage Defective Method, and Hypergeometric Sampling plans for small lot sizes of 200 units, or less. A further Appendix C is given, which gives case outline drawings with dimensions for T.O. cases and flat-packs, and finally, there is a Supplement 1 which cross references devices by type designators, to commercial types of similar characteristics. Lastly, and invoked by Appendix B there are two military publications, both of which also are invoked by MIL-STD-883A. These are:

MIL-STD-280. Definitions of Item-Levels, Item Interchangeability, Models, and Related Items.

MIL-STD-781B Reliability Tests, Exponential Distribution.

Respectively, these publications deal with standard terms & definitions for use with microcircuit devices, definitions of models both experimental, and production, and a technical treatise on reliability testing. This treatise, MIL-

STD-781B dated 28 July 1969, outlines test levels, and test plans for reliability qualification (demonstration), reliability production acceptance(sampling) tests, and for longevity tests. Tests are based on the Exponential, or Poisson Distribution, and are intended for those equipments whose mortality is considered to be characterized by such distributions. As might be expected, this STD also has a sub-tier, which will not be given here. Suffice it to say that there is considerable discussion as to the validity of the exponential distribution as a descriptor for device mortality. Experts in the field are challenging the distribution which has characterized electronic device mortality since 1957, as evidence appears to be growing that a normal distribution, is a more valid descriptor, and for long-lived items, the Weibull distribution is receiving wide use and attention.

3.2 Review by Section MIL-STD-883A: Thus far, the review of MIL-STD-883A has been concerned with the tortuous path through the dependency documents subtier. The manufacturer of microelectronic devices, must test his product in accordance not only with all of the sub-tier-requirements, but also he must use the methods and procedures set forth in the main text of MIL-STD-883A. This publication is divided into five (5) sets of major tests. The categories for these sets of tests are:

- o Environmental Tests (set 1001 thru 1015.1) 1
- o Mechanical Tests (set 2001.1 thru 2017) 2
- o Electrical Tests (digital) (set 3001.1 thru 3014)... 3
- o Electrical Tests (linear) (set 4001 thru 4007)...... 4
- o Test Procedures (set 5001 thru 5006)........... 5

Sets 2,3, & 4 may be considered as a primer of test methodology and techniques for the manufacturer of microelectronic devices. Not only are the test conditions cited for each test process, but also the limits are furnished for each parameter of interest. In many of the areas of interest to the military, illustrations of acceptable processing,and non acceptable conditions,have been included in the text. (e.g. 2010.2, 2011.1 Internal Visual,and Bond Strength,respectively) In the electrical Tests sets both digital and linear, the material furnished is illustrated by curves representative of pulse shapes, pulse rise and decay plots; and required test schematic diagrams; so that performance expected can be visualized clearly.

In Test sets 3 & 4 which deal with electrical testing, many of the tests furnish data of a parametric nature, which act as inputs to equations employed for the calculation of device parametric merit. All such equations german to a given test are furnished, and the variables are defined are listed together with their specialized associated symbology. To select an example at random:

Method 4001, is concerned with Input offset voltage and current and bias current. Clause 3.4 of Test Method 4001 deals with:

Input Offset Voltage Drift. viz: Measurement of $V_{io}1$ is made at Temperature T_1 per section 3.1 and a second measurement at T_2 of $V_{io}2$ is amde at the second temperature. Thus:

$$DV_{io} = \frac{V_{io}2 - V_{io}1}{T_2 - T_1}$$

It is not the intention of LMSC to review in this EM all of the test methods, their parametric implications, and expected outcomes per unit device. Such a practice would be not only time consuming, but of little interest to persons other than device designers and manufacturers. All of the test methodology represnts the best available state-of-the-art in the manufacture and proof-of-merit of microcircuits. As may be discerned from the relatively late issue dates of the major documents and their sub-tiers, to a large extent these publications have evolved as the necessity for the many test methods has been evidenced. Sets 1 and 5 of the 5 Test categories form the basis for this review, as it is these two sets which contribute most to the high cost of microcircuits used by the military and NASA, when contrasted with the cost of commercial versions of the same basic devices. The ensuing text consideres these two categories and their test sets in some detail.

3.2.1 Review of Method set # 1: This set of methods is concerned with Environmental Tests. The set includes:

1001 Barometric Pressure, reduced (altitude operation)
1002 Immersion
1003 Insulation Resistance
1004 Moisture Resistance (Current version 1004.1)
1005.1 Steady-State Life
1006 Intermittent Life

1007 Agree Life
1008.1 High Temperature Storage
1009.1 Salt Atmosphere Corrosion
1010.1 Temperature Cycling
1011.1 Thermal Shock
1012 Thermal Characteristics
1013 Dew Point
1014.1 Seal
1015 Burn-in Test.

3.2.1.1. Method 1001 Barometric Pressure, reduced (altitude operation) This test, routinely performed by the manufacturer at least on a small sample per device genus, is designed to reveal the presence/absence of voltage breakdown failures due to the reduced dielectric strength of air and other media/ insulating materials at reduced pressures. Tests are made at 15, 30, 50, 70, 100, 150, & 656K feet.

Comment: The need for a user to repeat this test is slight, and should only be an influence on the users' test program if the device genue is a new release.

3.2.1.2. Method 1002 Immersion: This test is intended to determine the merit of the seal of microelectronic devices. A hot bath is used over a wide range of temperatures, followed by a cold bath (usually water). Transfer time hot to cold must not exceed 15 seconds.

Comment: This should be a manufacturers' test only. It need not be repeated by users except in cases where device performance under operating conditions evidences seal deficiencies. Stock should then be tested by lot/batch on a sampling basis.

3.2.1.3 Method 1003 Insulation Resistance: This test is to measure the resistance offered by the insulating elements of a component/part to an impressed direct voltage tending to produce a leakage of current through, or on the surface of these elements. Impression voltage vaires from 10-1000 volts ± 10%.

Comment: This is another test performed routinely, which should not be repeated by a user unless his stock of devices evidences problems duing operation.

3.2.1.4. Method 1004.1 Moisture Resistance: Performance of this test is to permit evaluation in an accelereated manner, the resistance of parts and constituent materials to the deteriorative effects of heat and humidity conditions typical of tropical environments.

Comment: This test is performed as part of the qualification process by the manufacturer. Each family of devices is so qualified, and the test is repeated on a sampling basis for each batch produced per genus. Users need not repeat the test except in known cases of difficulty, and it has no pertinence to space-destined devices. Such devices are unlikely to experience the tropical conditions simulated by the test, and prior to launch the devices are afforded the protection of a controlled atmosphere in the Vehicle Assembly Building, as well as that of a shround when in payload ready-to-launch condition.

3.2.1.5 Method 1005.1 Steady-State Life: This test is performed to establish a representative failure rate (λ) for microelectronic devices, or to demonstrate the quality or reliability of devices subjected to specified conditions.

Comment: The test is adequate in all respects for the purpose intended. It is however, a reliability test primarily, intended to be performed by the mfr., under Government surveillance by one or more failure rate compilation agencies; such as Rome Air Development Center (RADC) Failure Rate Data service US Navy (FARADA), et al. A user routinely refers to data furnished by such an agency for the purpose of obtaining device failure rates, and should not undertake the expense of repeating the test unless there is evidence during operation of a device, or devices, that the life expectancy under stated conditions failure free, or the failure rate per surveillance period of operation, differ markedly from the Government published values, the period being shorter, or the lambda being considerably greater.

3.2.1.6. Method 1006 Intermittent Life: This test is similar to 1005.1 which preceeds it. The basic difference is that the failure rate is determined under conditions designed to explore the effects of cyclic variations in electrical stresses between the "on" and "off" state; and the attendant variations in device and case temperature.

Comment: All comments made for Method 1005 preceeding, apply equally to this test.

3.2.1.7 Method 1007 Agree Life: This test is intended to determine failure rate for a device, or genus of devices, where actual system application, and operating environment are simulated as closely as possible.

Comment: The term AGREE denotes Advisory Group for the Reliability of Electronic Equipment, and Indistry/Milatary organization formed in 1956, to update and improve relaibility. This test is specifically defined in the STD, is a composite

Test Methods 1005.1, and 1006. It is again a reliability test, and is required to conform with the requirements of MIL-STD-781 Reliability Tests, Exponential Distribution July 28,1969. The test should not be performed except by a device m nufacturer under surveillance of a Government quality/reliability investigating/certifying agency. A user should only undertake the test if government published data, and the test results obtained in operation for a device vary to a marked degree; and only then after informing a Government certifying agency of such an intention. (Most Government Contractors/device users have access to a U.S. Government Quality Assurnace Representative, who is either resident at the users' facilities, or can be contacted for visit/surveillance purposes in case of problems with a device, or genus of devices.

3.2.1.8. Method 1008.1 High Temperature Storage: The purpose of this test is to determine the effect upon devices stored at elevated temperatures for protracted periods, with no electrical stress applied. Test conditions range from 75°C to 400°C in 8 intermediate steps.

Comment: This test, performed as part of the device qualification process by the manufacturer should not be repeated by the user, particularly when devices are space destined. Where storage under elevated temperature conditions is not contemplated, the test constitutes an unnecessary expense.

3.2.1.9. Salt Atmosphere (Corrosion) Method 1009.1 : This test constitutes the accelerated laboratory simulation of the effects of seacoast atmospheres. Duration of the test period can be 24, 48, 96, or 240 hours.

Comment: Devices are protected by controlled atmosphere prior to space launch, either in a environmentally controlled building, a payload shroud, or both. Prolongued exposure to corrosive salt atmosphere thus does not apply, and the user need not repeat the test.

3.2.1.10 Method 1010.1 Temperature Cycling: The purpose of this test is to determine the resistance of a part to exposure at extremes of high and low temperatures, and to the effect of alternate exposure to these extremes. It was originally intended to simulate the transfer of equipment to and from heated shelters in arctic/antarctic areas. Manufacturers prform this test on a sampling basis for most device families.

Comment: Theuser need not repeat this test for devices whose operation will be in space environments, except in cases where the device(s) may be subjected to the variations imparted by solar heating/space frigidity.

3.2.1.11 Method 1011.1 Thermal Shock: The purpose of this test is to assess the resistance of the device to sudden exposure to extreme changes in temperature. All JAN TX types are subjected by genus to this test, on a sample/batch basis.

Comment: Device users should not repeat this test, except where such extremes are expected to be encountered by the equipment in which the devices are used; and only then when thermal shock problems become apparent in operation.

3.2.1.12 Method 1012 Thermal Characteristics: This test is designed to determine the case or junction temperatures (T_C or T_J) heat sink temperatures (T_S), thermal response time, or the thermal resistance (θ_{J-C} or θ_{J-A}) of microelectronic devices.

The test is performed routinely by the device manufacturers, who publish test conditions, test criteria, and the outcomes of such tests in the device data sheets. Users should not repeat such tests unless there is reason to suspect major departures from the published thermal characteristics when devices are operated under normal conditions. In such cases both manufacturers, and Federal surveillance/Quality agencies should be notified of the problem, and the intention of the user to undertake the tests.

3.2.1.13 Method 1013 Dew Point: The test is designed to detect the presence of entrapped moisture within the device package, in sufficient qualtity to affect device parameters.

Comment: This is a test to be performed by the device manufacturer. It should not be repeated by theuser, unless sharp parametric discontinuity is encountered with lots/batches of devices. These devices whose parameters are thus affected would be rejected by a user(s) and the test would be performed by physics of failure diagnosticians. Findings would be relayed to both Federal Quality agencies, and to the manufacturer concerned.

3.2.1.14 Method 1014 Seal: The design of the test is to determine the hermeticity of the seal of microelectronic devices with designed internal cavities. Essentially it is a leak rate test, performed by the manufacturer, and not intended to be repeated by the user.

Comment: Users should not undertake this test excpet in cases where problems are encountered.

3.2.1.15 Method 1015.1 Burn-in Test: The purpose of this test is to screen out marginal devices, to eliminate those with inherent defects, and those with defects which may become apparent as a function of elapsed operating time. If the test were not performed such devices might, in fact would be expected to be evidenced, as infant mortality, or early lifetime failures. The test is performed at maximum rated operating conditions to reveal time and stress dependent failure modes.

Comment: Considerable controversy surrounds the subject of screening and burn-in tests. Arguments for it include parameter stabilization, and the elimination of infant mortality items. Arguments con include the foreshortening of the life expectancy of the device(s), and the additional cost imposed upon the device by such tests. Yet further arguments rage over who should perform the test, manufacturer, or user? In practice, the test is performed by both parties frequently, and the costs are passed on to the ultimate user, the US Government. Since the tests are performed routinely by the manufacturer, under both user inspection, and government source inspection (GSI) LMSC is of the opinion that aerospace users, should not repeat the tests unless infant mortality problems arise with a given device genus.

3.2.2. Summary of Environmental Tests Review: The tests prescribed in this section of the STD are in general, well designed for their intended purpose; the determination of device operation under a wide range of environmental conditions. In almost all cases, the tests prescribed are performed routinely by device manufacturers who must qualify their devices before offering them on the open market. Problems arise when both manufacturer and user perform the same tests. Such dual performance arises from the invocation of MIL-STD-883A in the applicable documents section of RFPs released to the aerospace industry by Government agencies; primarily US Military and NASA. When the STD is invoked routinely, and with no specific direction given by such statements as this: "The contractor shall employ microcircuitry which complies with the standards set forth in MIL-STD-883A"; the user feels obliged to repeat tests to assure himself that the devices he proposes to use are indeed to the standard that has been specified. Even specification of Jan TX types is no guarantee of the merit of the delivered product.

Further, when the devices are incorporated into hardware at the Next Highest Level of Assembly (NHLA), they undergo repetitions of these tests, at varying levels of rigor, as called out by the overlap engendered by MIL-STD-810B. This not only imposes hardship on the devices, but also results in additional test cost burden to a program. It is an axiom that merit cannot be injected into

a device by repeated testing. LMSC contends therefore that unnecessary, costly replication of testing, is a practice to be discouraged.

3.2.3. Review of Method Set # 5: Method Set #5 is titled Test Procedures. As such it contains the specific procedures/techniques for control of tests included in sets 1 thru 4 of the STD. The listing of procedures is as follows:

- o Method 5001 Parameter Mean Value Control
- o Method 5002 Parameter Distribution Control
- o Method 5003 Failure Analysis Procedures for Microcircuits
- o Method 5004.2 Screening Procedures
- o Method 5005.2 Qualification and Quality Conformance Procedures
- o Method 5006 Limit Testing.

3.2.3.1 Method 5001 Parameter Mean Value Control: This procedure is concerned with the recording of Test data amassed from the conduct of any, or all tests, conducted as per the prescriptions of Method Sets 1 thru 4. It is not intended to apply to devices whose parameters are between specified limits, but rather to lots of devices where the average of a given parameter, or mean value is controlled at some required level. In simple terms, a lot so controlled can be considered as a "matched set".

Comment: In order to provide the highly controlled JAN-TX designated product, group/batch testing for this device is necessary. In essence minima and maxima over a small range of extremes are set upon parametric means. From a given batch of devices, the yield under this form of controlled test procedure is small. This adds to the cost of the product, but does provide a highly uniform population lot-to-lot. As a routine design practice, such close control of parameters is to be discouraged, as unnecessarily costly.

3.2.3.2. Method 5002 Parameter Distribution Control: This procedure defines a technique for assuring a normal distribution for any test method listed in sets #3 & 4 of the STD. Essentially, this is a statistical technique for assuring that tests undertaken to assure parametric conformity with the prescribed limits do not vary more than ± 1 std. deviation from the parametric mean. In particular, not less that 12% but not greater than 18% of untis tested will fall below the mean - 1 sigma limit, and not greater than 18%, but not less than 12% of units tested will fall above the mean + 1 sigma limit.

Comment: This is a severly restrictive requirement, and the yield from any given lot or set of lots is small. The costs of such normalizing of parameter distribution are high, and the practice should be doscouraged unless proof is furnished to the Government of its essentiality.

3.2.3.3. Method 5003 Failure Analysis Procedures for Microcircuits: This procedure sets forth in detail the methods for post-mortem examination of failed microelectronic devices. The methodology employed is often called physics of failure analysis, and employs advanced analystical techniques such as microscopy, metallurgical analysis, chemical analysis, radiography, photo micrography, et al. Details of required apparatus are specified, as well as the particulars of all analytical tests and processes to be employed.

Comment: While such analysis is undertaken at the facilities of device manufacturers, not all device users are equipped to undertake anayses of this level of sophistication. The process is costly in terms of equipment and personnel required. Such analysis should not be undertaken by device users, unless specifically required by contractual obligation to the Government customer. The Government customer should review each RFP or other contractual vehicle, to determine whether or not the data yield from such failure analysis is worth the cost, in terms of failure mechanisms, and/or trends that may be revealed, prior to inclusion of the techniques, and release for bid/implementation of the contractual vehicle.

3.2.3.4. Method 5004 Screening Procedures: This method establishes the screening procedures for total lot screening of microelectronic devices; to assist in achieving levels of quality and reliability commensurate with the intended application. Three (3) levels of screening rigor have been assigned arbitrarily , and these are described in MIL-HBK-217A Military Handbook for Standardization of Reliability Prediction. Over simplified, the levels are:

A. Extreme Rigor
B Rigorous
C Minimal Screening

Class B is to be used where no other class is prescribed.

Screening Tests are tabularized together with the percentage level at which the screening is to be applied, for all three classes.

Comment: The screening process has worked well since the inception of microelectrnoic devices. It is an open question whether or not Class B screening has had better value to the industry than Class C, as the latter class has seldom been used. The process is costly, to implement, and the yield per lot

is directly dependent upon the screening level applied. It is not suggested that screening be discontinued, but rather than a uniform level of quality and reliability be established for the devices by genus, and a standard screening process be applied to all dependent upon this figure of merit.

3.2.3.5. Method 5005.2 Qualification and Quality Conformance Procedures: This method establishes qualification, and quality conformance inspection procedures for microelectronic units, to assure that device and lot quality conforms with the requirements of the applicable procurement documents. This procedure involves producer, user, and ultimate user, the US Government. The method cites: Tests to be performed as part of the inspection process, and tabularizes them into Groups and sub-groups. Test procedures are cited for both monolithic, and multi-chip microcircuits, and requirements for sample selection, sample disposition, accelerated quality conformance testing, and substitution of tests/test sequences also are given. The requirements for bond strength and data reporting are specified, and finally, the exact contents of the procurement document are set forth.

Comment: The procedure is usually implemented in association with the screening process procedure, and the costs are in direct proportion to the Lot Tolerance Percentage Defective (LTPD). The tighter the LTPD the greater the inspection costs, and in turn, if the inspections are carried out by all three involved parties, producer, user, and Government, cost escalation is rapid. It is strongly recommended that the tests be carried out once only in as many cases as possible, with test surveillance by both user, and Government QA representatives.

3.2.3.6. **Method 5006** Limit Testing: This method stipulates means for establishing or evaluating the maximum capabilities of microelectronic devices, including such capabilities as absolute maximum ratings (from which safe design limits may be derived), maximum stresses which may be applied in screening or testing without causing degradation, and sensitivity to particular screening and testing stresses, and the associated modes or mechanisms of failure. The types of test are included as are the sample sizes required for each test. The method recognizes that the tests are destructive in nature, time consuming, and costly. The testing is not expected to be conducted on all procurements, but is advocated for testing new types, and for the assurance of high device reliability.

Comment: LMSC strongly recommends that this type of testing be conducted only on new types of devices, and only to the extent necessary to establish limits on critical parameters. The method itself is well designed as a procedure, and considers all essential criteria.

4.0 Cost Impact of MIL-STD-883A: Early in this EM, in paragraph 1.3, reference was made to the fact that the application of MIL-STD-883 drove program costs approx 7.5%. It was inferred that 1.5-2.5% of program cost might be saved by modification of both MIL-STD-883A, and MIL-STD-810B. The high program cost figure attributed to the application of MIL-STD-883A came about for several reasons as listed below:

1. The two programs for which any microcircuit cost data were available for study were MVM-73, and AE (Atmosphere Explorer).
2. These programs are among the very first to avail themselves of on-board equipment using MSI and LSI (Medium Scale and Large Scale Integration).
3. The on-board equipment employing these techniques, and the microcir-uits thus involved was of relatively new design.
4. At the time of spacecraft design, manufacture, integration and testing, microelectronics technology was expanding and being refined. Similarly the MIL-STD was being evolved in terms of test methodology, device test criteria, acceptance criteria, LTPD levels, et al.
5. In 1971 and 1972, and even earlier in 1969 and 70 considerable trouble was being experienced in the aerospace industry with microelectronic devices. The yield per lot tested was low, and each successive test further reduced the lot size; lead bonding was a problem of major magnitude, with leads falling off as a result of improper processing and controls, and long delays were being experienced in obtaining given devices from many device families. As a result device costs were escalating rapidly.
6. As an outcome of the conditions enumerated in paragraph 5, each device lot was subjected to extensive testing by the device manufacturers, the device users at the primary equipment level, and the primary equipment integrators at the subsystem and system level. Further evidential tests were required for device type certification by US Government QA representation.
7. Test programs may have been too rigorous, as the AE contractor reported a yield of less than 40% on several device lots tested.

All of the above factors combined resulted in the costs ascribed to these prog-

rams, and finally the value of 7.5% TPC was an estimate based on data of some dubiety. The real figure is unknown seemingly to anyone, and may be less than the one deduced. It is believed that even the curtailment of one step in the multiple replications of testing would account for the savings value cited.

5.0 Specific Recommendations: LMSC believes that adoption of the following recommendations will materially reduce the high cost of environmental testing at both the device, and the system level:

- o. Review and combine the two Stds into one conjoint NASA standard to cover all aspects of environmental testing at all hardware levels.
- o Specify in the RFP, or other contractual document, exactly what testing, at what levels the Government expects to see. Make the contractor's test plan the binding document for what testing is to be done, at what time, and to what degree of test replication.
- o Standardize device tests as much as possible as to methods, replications, sample sizes, parameters, et al. The present test methods and standards tend to be too general.
- o Minimize test replications to the maximum extent possible, and in all cases where a test at the next higher assembly level will suffice to demonstrate merit, use this method to curtail the test load.
- o Minimize the amount of test data reporting, and test documentation required at all program levels.
- o Assure that QA and Reliability requirements specified are adequate for the program, not the best possible, as is the current practice.
- o Standardize the number of devices available for a program, and do not design new ones merely for the sake of doing so.

Finally, until such time as the present MIL STDs are re-written, and re-issued, assure that the documents listed as controlling the overall test process are the latest issue possible, and a list of tests not-required (exceptions list) is appended to each purchase order, particularly at the device level.

ENGINEERING MEMORANDUM

TITLE: A "New-Look" Standardized Work Breakdown Structure (WBS)	EM NO: LCPP-17 REF: DATE: December 5,1975.
AUTHORS: D.L.Hannaford.	APPROVAL: ENGINEERING D L Hannaford SYSTEM ENGRG

This analysis is presented in two (2) parts. The first, Part 1, furnishes a general overview of the conception, prosecution, redirection, and accomplishment of the task; whereas the second, Part 2, is a detailed technical discussion of the subject.

Part 1

1.1 Task Objectives: The task was undertaken as the fifth (5th) of a series of technical analyses, each a sub-task of Study Task 2. As such the task had two (2) objectives:

(1) Generation of a "New-Look" Standardized WBS

(2) Generation of a "Users' Handbook" to assist with the implementation of the WBS for future spacecraft programs.

A preliminary concept was prepared and documented, and a review was made by NASA and LMSC of this concept. It was the consensus of opinion that due to the limited period of the study, the two objectives were unattainable. Modified objectives were proposed by LMSC, and NASA concurrence was obtained for the modified objectives which were:

(a) Analyse and document the merits, and problems implicit in the development and implementation of a Standardized WBS.

(b) Establish means for tracking/recording data to evaluate the cost impacts of Low Cost Practices using any type of WBS.

1.2. Task Background: Identification and quantification of high cost-driving practices, based upon historical programmatic, and cost data; from past and on-going unmanned space programs, were, and continue to be, the major objectives of the NASA Low Cost Program Practices Study contract undertaken by LMSC. Although many of the high cost practices of past programs have been quantified satisfactorily, many others have been identified as suspected high cost practices which could not be quantified from historical records. This lack of adequate cost and programmatic data was evident in a data sampling of thirty nine (39) NASA & DoD historical programs. The data inadequacy revealed by this sampling process was verified by a survey of more than seventy (70) program managers, functional managers, and cost analysts, within NASA and the aerospace industry.

Fifty seven percent (57%) of those interviewed believe that programmatic cost data existing within their organizations are not adequate for quantifying impacts of program practices, nor for making comparisons between two or more programs. Nineteen percent (19%) believed that their data were adequate, and the balance expressed no opinion.

It appeared evident that that some NASA practices related to program WBS contributed directly to this lack of adequate cost records. Furthermore, traditional practices tended to preclude quantification of both high and low cost-driving practices in the several functional areas of: Systems Engineering & Integration, Flight Support Equipment, Ground Support Equipment, etc.
The scarcity, and inadequacy of the historical data, and the fact that NASA is in the process of conversion to more cost effective methods of conducting near-term, and future space programs; gave rise to the conclusion that work should begin immediately on the development of a "NEW LOOK" WBS. This programmatic work/cost analysis tool, together with its associated implementation directives for Low Cost Practices, will be of material benefit in prosecution of the NASA policy of total program cost effectiveness.

1.3. "NEW-LOOK" WBS - Capabilities Desired: The desired capabilities inherent in a New Look WBS may be listed as follows:

(a) To provide a candidate NASA STANDARDIZED WBS for future unmanned programs, and thereby preclude the added costs of providing new, and different WBSs in several iterations, each tailored for each new program.

(b) To provide a standard framework, with detailed formats for collecting, and tracking all program costs from several organizations at different locations, (These include NASA centers, prime contractors, and subcontractors) in a manner that permits NASA to sum all program costs rapidly.

(c) Provide an overall capability for the comparison of the costs of various program elements, as well as total costs among programs; such that cost impacts of new low-cost practices under implementation, are reflected in detail.

(d) Provide the capability for tracking and quantifying the cost impacts of low cost practices, such as the use of standardized spacecraft components, and low cost management practices, now being developed under the direction of NASA/HQ Low Cost Systems Office (LCSO).

(e) To emphasize tracking/recording of all labor costs.(approximately 65% of each NASA budget dollar is spent for labor; and labor efforts are most directly impacted by low cost practices).

1.4. Results Summary: The significant results of this study subtask are summarized as follows:

o LMSC was unable to meet the initial program objectives of development, and documenting of a Standardized WBS and Users' Manual, within the time constraints of this study segment.

o LMSC did develop a Standardized WBS Concept, believed to be adequate for implementation in unmanned spacecraft programs, subsequent to full development of the concept.

o Also developed were concepts for the establishment of programmatic records which will provide a better history of program performance than do current record keeping practices. These new records will list low cost program practices used in work packages, and will summarize work package quantifiable data so that evaluation/quantification of the cost impact of program practices can be effected. (The conceptual records envisioned can be used with, or without a Standardized WBS)

1.5. Conclusions: Several conclusions resulted from the Study subtask, and these may be listed as follows:

- o LMSC under-estimated the task of development of a Standardized WBS, and merely added to the complexity of the task by incorporating the requirement for tracking/recording those details permitting the quantification of Low Cost Program Practices.
- o The prosecution of the task did allow the establishment of a basic concept, and firm bases for the development of a standardized WBS on some future occasion.
- o The basic concept established for standardization provides adequate flexibility within the work package framework envisioned; to faciliate and accommodate the small differences expected to exist among unmanned spacecraft programs.
- o Implementation of the Standardized WBS concept could save NASA several million dollars per annum. Traditionally, these monies have been spent

on the preparation of "tailored" new families of WBSs for each new space program.

- Implementation of the concepts defined in this study, will provide improved visibility into program performance, as well as providing better programmatic records to facilitate cost evaluation. Further, current cost collection and reporting systems in use by NASA, will not be affected significantly as regards existing forms and procedures.
- Cost effective development of the concepts set forth in this study will require the participation of NASA personnel on a day-to-day basis. Such participation will facilitate the adoption of incremental decisions, and definitions, in terms of modus operandi, and problem solutions.

1.6. Recommendations: LMSC has formulated several recommendations as outcomes of this subtask of the study. These are:

- That efforts be continued to develop and implement a Standardized WBS family for NASA/Contractor use on unmanned spacecraft programs.
- That a small team of NASA and Industry specialists be established. Such a team would be engaged in full-time development and implementation of an integrated family of WBSs, to cover all NASA and aerospace contractor effort on future unmanned spacecraft programs.

Part 2. Detailed Technical Discussion:

2.1. Technical Overview: This section of the EM sets forth the premises upon which this subtask was formulated, the work actually accomplished, and the rationale which was responsible for the abandonment of the original task objectives, and the adoption of those which were implemented during the course of the analysis.

2.2. Assumptions: Listed hereunder are the assumptions which underlay the original subtask concept:

(a) NASA historical records are inadequate for the quantification of the cost impacts of many high cost practices applied to past programs. The same inadequacies prohibit the comparison program-to-program of the costs and practices which have been used.

(b) Historical cost records have proved to be inadequate for the cost-effective real-time management of programs.

(c) NASA practices in the areas of Program Work Breakdown Structures (PWBS) and Contract Work Breakdown Structures (CWBS) contribute directly to the lack of adequate historical cost and programmatic records.

(d) These shortcomings could be eliminated by modifying WBS practices in such a manner that the size, complexity, and proliferation of WBSs could be reduced to some standard minimum.

(e) Traditional NASA practice has been to fund the tailoring of a separate WBS for each program undertaken. Much of the funds spent for such a practice may be saved by the development of a Standardized WBS applicable to the majority of future unmanned spacecraft programs.

(f) It is desirable to log the implementation, and potential impacts of low cost program practices, in all future program records, thus assuring that such records are available for post-program cost/performance analyses/evaluations.

(g) Methods developed for tracking costs of program practices should be compatible with existing contractor cost-reporting systems, such as the USAF validated CSCSC (Cost & Schedule Control System) in use at most aerospace contractors' facilities.

2.3. Analysis Approach: The approach adopted for the analysis was based on both the assumptions made, and the desire to incorporate those capabilities and characteristics considered essential. A multi-step analysis was undertaken, and the several steps are listed as follows:

(a) Analyse NASA and DoD Guidelines & Control Documentation related to WBS formulation, implementation, and use; to assure compatibility of the potential NEW-LOOK WBS with both the intent of such documents, and the NASA Agency-Wide coding system.

(b) Lay out a preliminary concept for scoping the overall task at the program level, and indicate the method of incorporating the desired capabilities.

(c) Analyse CWBSs from both historical and on-going programs to select, and incorporate their best features into the New Look

concept, while avoiding apparent errors & shortcomings.

(d) Establish a preferred CWBS concept for proposal as the candidate Standardized WBS for unmanned spacecraft programs.

(e) Prepare a Users' Manual, including a WBS dictionary, to support the preferred CWBS concept.

(f) Consult with LMSC financial management personnel to evaluate the implementation compatibility of the evolving WBS concept, with the LMSC government-validated CSCSC program.

2.4. Research, and Compatibility Analysis: NASA and DoD guideline and control documentation concerning WBSs was reviewed and extensively researched to determine what methods were reccommended for formulation and ultimate use. Outcomes of this research, and their pertinence to this analysis task are listed as follows:

(a) Five underlying reasons for the NASA decision to report costs at the spacecraft and system level only, are:

(i) This summary level was considered adequate for program management in most cases.

(ii) The level selected for cost reporting must be contractually binding.

(iii) Lower levels are not made contractually binding, and they are uncontrolled by NASA. This permits flexibility for the contractor to make changes, and obviates the necessity for contract changes whenever a lower level WBS element is changed.

(iv) Lower level WBS elements dealing with "program critical items" are made contractually binding on a "per case", or an "as needed" basis only.

(v) To avoid the costs incurred in reporting at lower levels, and to avoid also, a multiplicity of contract changes.

Election by NASA of the listed options has contributed to development of inadequate programmatic cost records, when these are considered from the standpoint of quantifying the cost impact of program practices.

The exercise of such options also may cause conflict between continued use of current WBS practices (which provide considerable program flexibility, but produce questionable historical records) and use of the proposed LMSC WBS practices reccommended as alternates. These alternate practices may impose restrictions upon program flexibility, but will produce better program records. Such records can only improve cost visibility for future spacecraft programs. There may be a compromise possible between established NASA WBS practices, elected from among the options listed, and the LMSC proposed alternate practices. If such a compromise is made it may prove of greater benefit to NASA than either the established practices or the proposed alternates.

(b) Requirements already exist for the development of separate WBSs for not only each NASA field center, but also for each prime or associate contractor. Nothing is mentioned in the literature research about these WBS versions being developed within some common framework. A common framework would permit not only rapid NASA summation of all program costs, but also the easy identification of duplication of effort.

(c) Requirements for providing the capability to track and report costs down to the work-package level already exist; although the option to use this capability is seldom exercised. This finding is significant with respect to tracking of program practices as, tracking cost impacts of standardized components, must start at the component level; and the tracking of cost impacts of management practices must start at the work-package level. These basic requirements compell the conclusion that tracking of the cost impacts in a literal sense would be very expensive, if not prohibitive, in terms of time, dollar expenditure, and personnel effort. Such a conclusion mandates an explanation of the LMSC use of the terms "track, tracking, and tracking/recording." As used in this report, these terms signify <u>recording or providing a means of traceability for analytical purposes</u>.

(d) Another potential conflict of the LMSC approach versus the approaches set forth in the DoD/NASA guideline documentation, arises from the LMSC proposal to incorporate the capability to report indirect labor into the WBS work-packages, in addition to the direct labor costs within NASA and the aerospace industry. Such reporting would facilitate the evaluation of program practices cost impacts on all <u>labor activity</u>. However, it is most unlikely

that this proposal will be implemented, because of the conflict it would occasion with the many existing aerospace management, and business practices.

2.5. Review of Existing WBS Examples: WBS examples, and their associated Dictionaries, were obtained from several programs, and subjected to critical review. Desirable features were extracted from these examples for incorporation into the LMSC Preferred Conceptual WBS. This preferred concept was intended to constitute the selected candidate for Standardization, but was not completed, as completion was impossible within the constraints of the study schedule. The review included:

- o MVM-73 Program WBs
- o LST Program WBS
- o SEASAT Proposal WBS
- o PELSS Proposal WBS (Precision Emitter Location Strike System)
- o SESP 71-2 WBS (Proposal & Program)
- o DSCS III (Defense Satellite Communication System) Proposal WBS
- o SUS (Solid Upper Stage for Shuttle) Proposal WBS

2.6 System Descriptions Review: Selected system description documents were reviewed, as well as the LMSC Cost and Schedule Performance Reporting System, CASPER. The object of this review was to ensure compatibility of the candidate WBS with the capabilities of this mechanized reporting system. While this review was informative in a general sense, no firm conclusions as to compatibility of the WBS concept could be formulated. However, the information of general value is listed below:

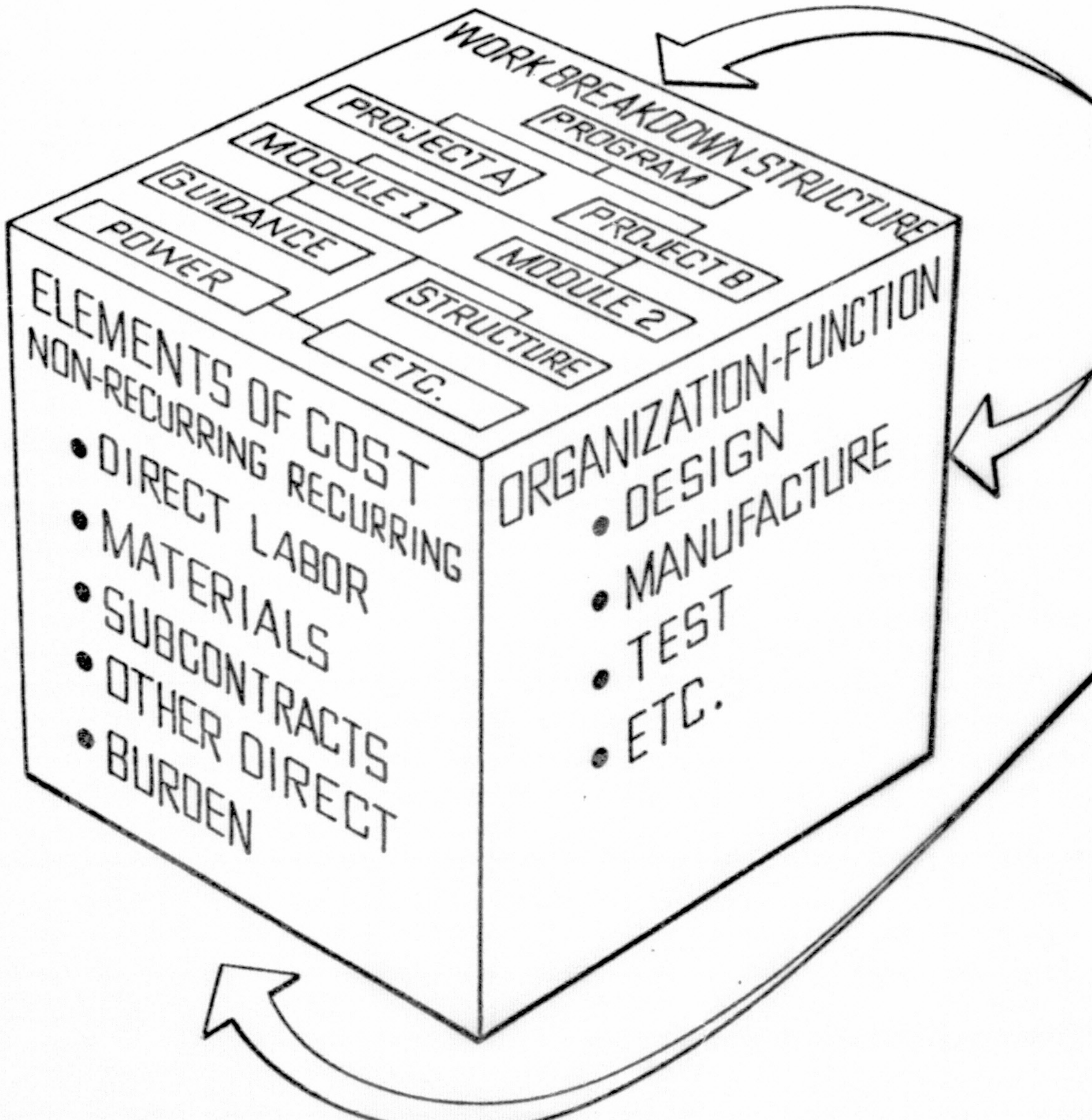
- o Storage capacity, and capability for numerical manipulation of the computer is no limitation for the WBS concept.
- o The CASPER system can accommodate WBS requirements of 12-1500 time-card type charge numbers, and up to 3000 cost accounts, where a cost account is defined as an identifiable mechanism for summing elements of program costs, such as labor, etc. These limits are based on practical experience which has demonstrated that increasing the number of cost accounts, or charge numbers,beyond these limits tends to reduce the accuracy of the accounting process. Further, the cost of rechecking all the human effort involved in accurate coding of these numbers, increases dramatically, when the limits are exceeded.

o Yet another practical limitation on the system is the quantity of line items of cost data that program managers, and cost analysts can use effectively, at monthly, or quarterly intervals of program reporting.

2.7. NEW-LOOK WBS Preliminary Concept - Total Program Level: Figure 2-1 which appears on Page 10, is extracted from NASA Document, NHB 9501.2A, and depicts the normal NASA Reporting Structure Matrix. From this foundation, an overview of the NEW-LOOK WBS Preliminary Concept was derived, showing WBS data handling at the Total Program Level. An illustration of this concept appears as Figure 2-2, Page 11. Elements A, B, & C, represent the same items in both figures, and are self-explanatory.

2.7.1. WBS Family: Element D of Figure 2-2 advances the concept of using a standardized set, or family of WBSs, and includes all organizations involved in a program; i.e. NASA installations, Prime-Contractors, Associate-Contractors, and Major Subcontractors. The study schedule did not permit the construction of trial layouts demonstrating the method of configuring a WBS family to correlate all elements on a total program basis; however, standardization to the maximum extent possible appears to be a cost effective step. In accordance with existing NASA guidelines for WBS preparation, each organization involved is required to develop a new WBS tailored specifically for each new program. While the WBS is prepared new for each program, the type of work performed, and the organizations performing it, are usually repetitive program to program, for each functional division of labor. Repetition of the types of work performed, is due to the practice of grouping a number of semi-fixed skills into a functional division of labor; and is due further to the repetitive nature of the types of end-items, and services required from these functional groups during the execution of every program. This repetition of tasks within each functional division of labor provides the basis from which a standardized set of work-packages for each labor division may be developed. Adoption of this concept would mean that standard forms could be developed for each labor division, and these could be used for all programs thereafter. The forms would provide:

1. Descriptions of tasks performed routinely.
2. Descriptions of program peculiar tasks (if any)
3. Descriptions of task outputs; i.e. end-items and/or services
4. Numerical data such as quantities of end-items, man-hours required,



- WBS/PRODUCT–END ITEM ORIENTATION TO HARDWARE, PRODUCT, SERVICE OR TASK
- ORGANIZATION/FUNCTION–THE ORGANIZATIONAL ELEMENTS AND THE FUNCTIONS INVOLVED IN THE TOTAL CONTRACT EFFORT AND OR SPECIFIC WBS ITEM
- ELEMENTS OF COST–NATURAL CLASSIFICATIONS OF COST, ACCORDING TO THE NATURE OF THE EXPENSE INVOLVED.

REPORTING STRUCTURE DATA MATRIX
FIGURE 2-1

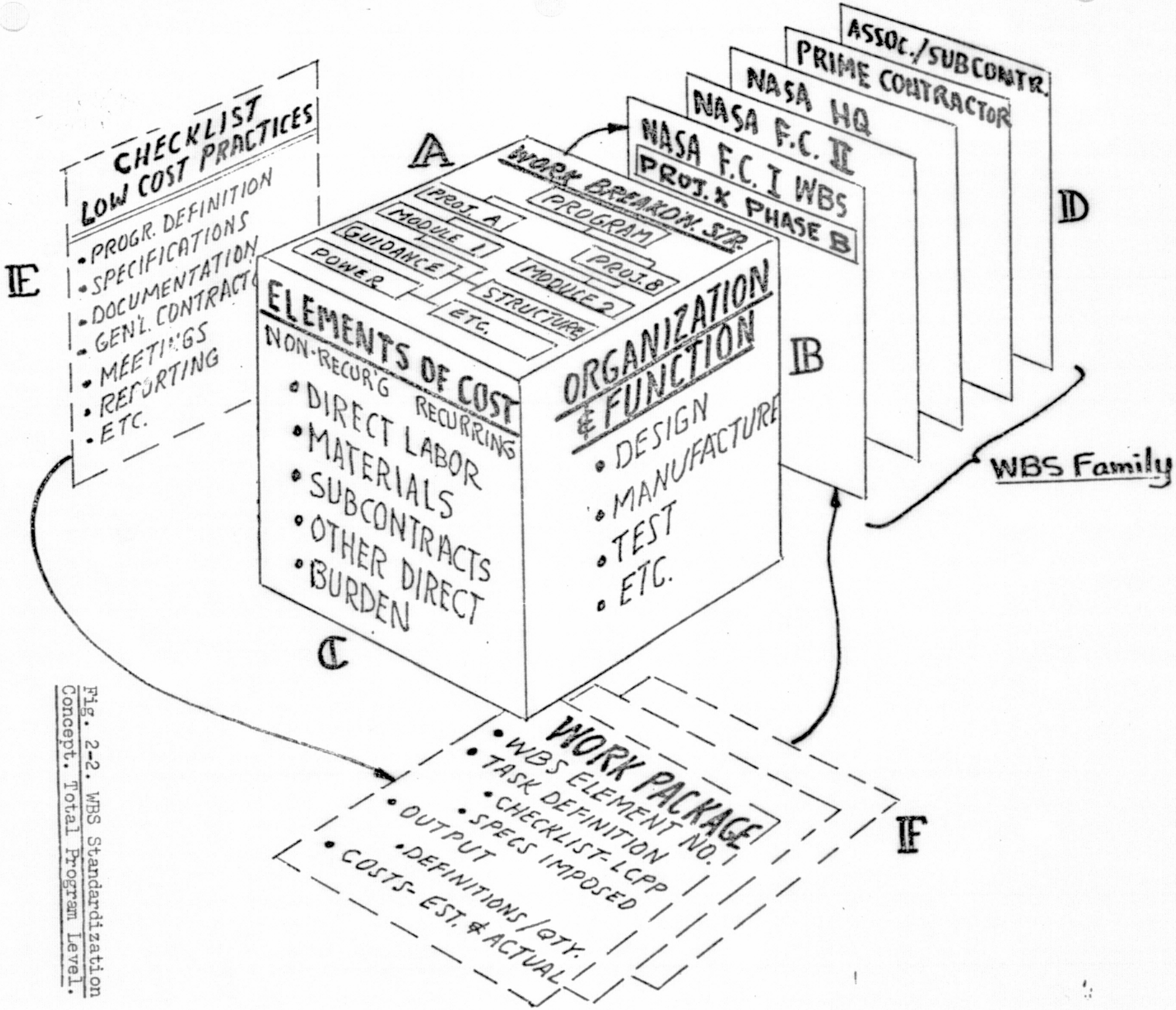


Fig. 2-2. WBS Standardization Concept. Total Program Level.

(with columns for initial cost estimates and final actuals)

5. Explanations of programmatic changes, which are causative of adjustments to any of the numerical data.

This definition of a work package is different from that given in NHB 5600.1, but could be compatible with the DoD definition furnished in AFSCP/AFLCP 173-5. Both definitions can be altered without any major impact on program cost accounting methods if NASA deems program economies essential. All of the foregoing premises suggested that the logical method for structuring a standardized WBS was to use the functional divisions of labor as key elements. This method was adopted to structure the standardized WBS version which appears elsewhere in this EM.

2.7.2. Checklist- Low Cost Practices: Element E of Figure 2-2 presents a standard checklist of Low Cost Practices (SCLCP). Figure 2-3, appearing on Page 13, provides an example of an SCLCP, whose purpose is to record all low cost program practices that NASA may wish to implement for future programs. The list is standardized, and controlled so that it may be adopted and used throughout NASA. NASA-wide adoption of a standardized, controlled, list of practices, will assure that the list receives regular up-dating and revisions. For recording and tracking purposes, such a list would be attached to each work-package, to show the quantity and types of Low Cost Practices incorporated therein, and the degree of implementation intended. A further use of the list would be the promotion of the use of low cost practices, and to facilitate NASA/Contractor general program planning.

2.7.4. Work-Package Record Summary : Element E of Figure 2-2 illustrates a Work Package Record Summary to be used as a historical record-keeping method. The summary would record orientation, and numerical data pertinent to work task(s) described in each work package. Examples of data to be recorded are:

- o SOW numbers.
- o WBS element numbers.
- o Quantity and type of specifications imposed
- o Specific outputs/end-items & quantities of each expected to result from the work to be performed.
- o Task listings of work as part of the work packages

CHECKLIST - LOW-COST PRACTICES PROGRAM/PROJECT: ______ PHASE: ______		DEGREE OF IMPLEMENTATION		
LCP NO.	PRACTICE	FULLY APPLIED	PARTIALLY APPLIED ⚠1	NOT APPLIED ⚠2
	RFP's			
1-1	Complete Definition of Program Elements in Phase C/D			
1-2	Preliminary of RFP by Contractor			
1-3	Use of RFP to Encourage Lower-Cost Response			
1-4	Streamline Response Data Required by RFP			
1-5	Minimum Acceptable Mission/System Performance Reqts.			
1-6	Lower-Cost Alternate Proposals			
1-7	Reduce Reqts. for Contractor Plans			
	DOCUMENTATION			
3-1	Use Low-Cost-Driving DRL's			
3-2	Documentation-Need Evaluation Form			
3-4	Use Direct Contact in Lieu of Paperwork			
3-5	Use of Contractor Internal Documentation			

Approved: ______
Program/Project Manager

⚠1 Explain on separate sheet for each LCP item so classified.

⚠2 Provide explicit reason and obtain deviation approval from NASA/HQ, Low Cost Systems Office, for any single LCP so classified.

Figure 2-2 - SAMPLE STANDARD CHECKLIST FOR LOW COST PRACTICES

- o Cost estimates for each task, and each total work package.
- o Functional divisions of labor performing each task.

Data recorded on this summary, together with the check-list of Low Cost Practices to be attached to it, constitute a mimimal practical set of historical data for the evaluation of cost impact of Low Cost Program Practices for future programs. Further, such data will provide for comparison between, and among, two or more programs.

2.7.5 Discarded Concepts: In addition to those previously discussed, the initial concept contained at total program level, two ideas which were subsequently abandoned. The first was the use of a separate WBS devoted to labor costs, and emphasizing both their magnitude, and the impact of program pratices upon them. The idea was abandoned early in the analysis, because the increased paperwork proved to be prohibitive in the light of the value of the additional emphasis so gained. Computer print-outs isolating labor costs from other costs incurred, can be obtained from most cost reporting systems, at less expense. The other idea was to treat indirect costs in the same manner as the direct-labor cost elements are handled. Such treatment was expected to expedite the evaluation of the cost impacts of program practices on total program costs; not only more completely than is presently done, but also more accurately if possible. This idea was found to be impractical since the effort required to change indirect labor practices throughout the aerospace industry would be extremely costly, and time consuming. Moreover, the desired payoff in terms of practice quantification improvement might not prove significant, and realization of the NASA initial purpose in quantifying cost impacts of program practices can be effected without this idea being adopted.

2.8 WBS Standardization Concepts - Spacecraft Project:

2.8.1 Cost Reporting at the Component Level: Reporting costs at this level is desirable , as visibility of costing details will be improved. Further, the cost impacts of low cost program practices such as use of standard components can be quantified, when future programs are costed at this level. Most of the standardization concepts set forth are equally applicable to the reporting of subsystem, and system level costs; the traditional NASA mode of operation.

Sample WBS layouts included in this EM include ideas obtained from review of WBSs, and WBS dictionaries describing several historical, and on-going programs.

2.8.2. Major Observations & Interim Conclusions:

(a) There is no "Best-Way" to organize a WBS.

(b) Program-peculiar, "tailored" WBSs reviewed, all appear to have emphasized visibility in some areas of programmatic/costing activity, while providing "less than average visibility" in other areas.

(c) All of the WBS examples reviewed, evidenced "Forced-Fit" in several areas; i.e. forcing work tasks into a particular block, which could have been fitted into any one of several other blocks, with equal logic.

(d) The WBS dictionaries reviewed exhibited "Forced Grouping", that is, combining a number of functions/tasks, so that the overall number of WBS elements, and presumably the subsequent number of work packages, can be kept to some manageable quantity.

(e) It would appear, that by necessity, similar shortcomings must beset all standardized WBS concepts.

(f) Standardized WBS concepts must exhibit equal visibility in all program areas described by the concepts.

(g) The uniformity of programmatic visibility, and the cost comparison of two or more programs, could be improved by:

(i) Standardizing the manner in which "Forced-Fits" are made

(ii) Standardizing the WBS level at which these compromises are applied.

These two measures would not degrade the visibility of cost parameters within a single program.

2.8.3. WBS Layouts (Partial): Figures 2-4, 2-5, & 2-6 which appear on Pages 17, 18, & 19 respectively, represent partial layouts included to facilitate discussion of WBS concepts. The figures are preliminary in nature, and do not furnish information regarded as finalized for purposes of standardization. Figure 2-4 depicts a conceptualized version of a spacecraft project level WBS, considered adequate in scope for a very large unmanned spacecraft project. The relationship is shown of the spacecraft project to the overall program, as well as the conventional WBS levels, and the major system level summation

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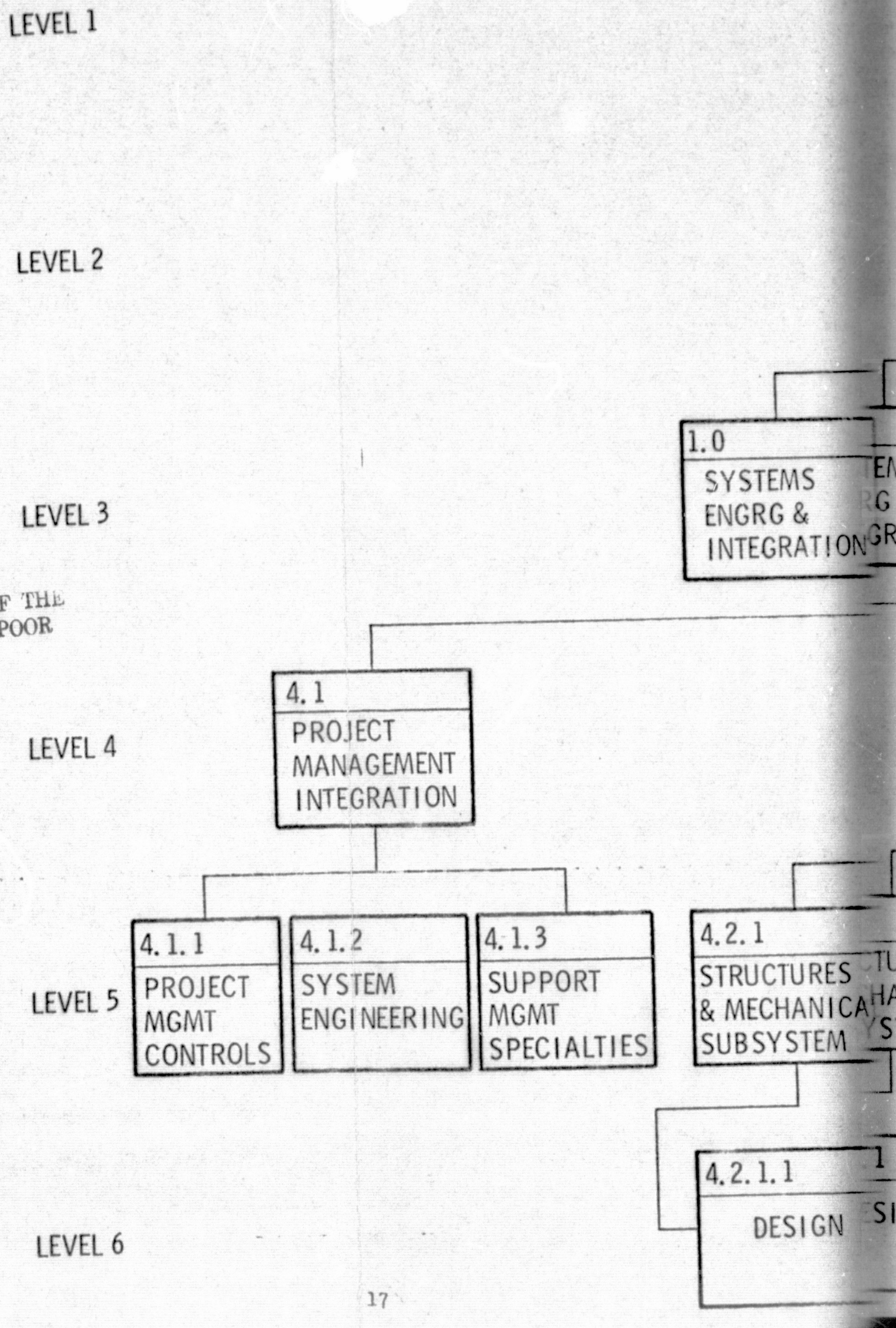
blocks within the spacecraft project. System level blocks 4.1, & 4.3, are not discussed. Standardization concepts discussed under block 4.2 Spacecraft Development are generally applicable to blocks 4.1 & 4.3, hence the discussion is confined to block 4.2. and its details only. Subsystem level blocks 4.2.1 thru 4.2.10 are believed to be adequate for standardization in unmanned spacecraft projects. Figure 2.5. presents an extension of the Structures & Mechanical Subsystem block 4.2.1, and Figure 2-6 presents an extension of the Spacecraft Integration and Assembly Subsystem Level, Block 4.2.10. Components, and other component level end-items associated with the subsystem blocks are displayed as sub-tiered items of the subsystems. Major functional divisions of labor necessary to the development and/or integration of the subsystems, and sub-tiered elements of hardware/software, are displayed on a WBS level below the subsystem level. Specific tasks to be performed by each functional division of labor, are displayed as sub-tiered items under each functional division of labor. As previously stated, the repetitive nature of the end-items, and services required in all unmanned space programs; and the repetitive nature of all tasks to be performed to accomplish the end-item production, and service requirements; provide a logical basis for standardizing work-packages by functional division of labor. Work-package standardization, in turn, provides the basis for standardization of the WBS.

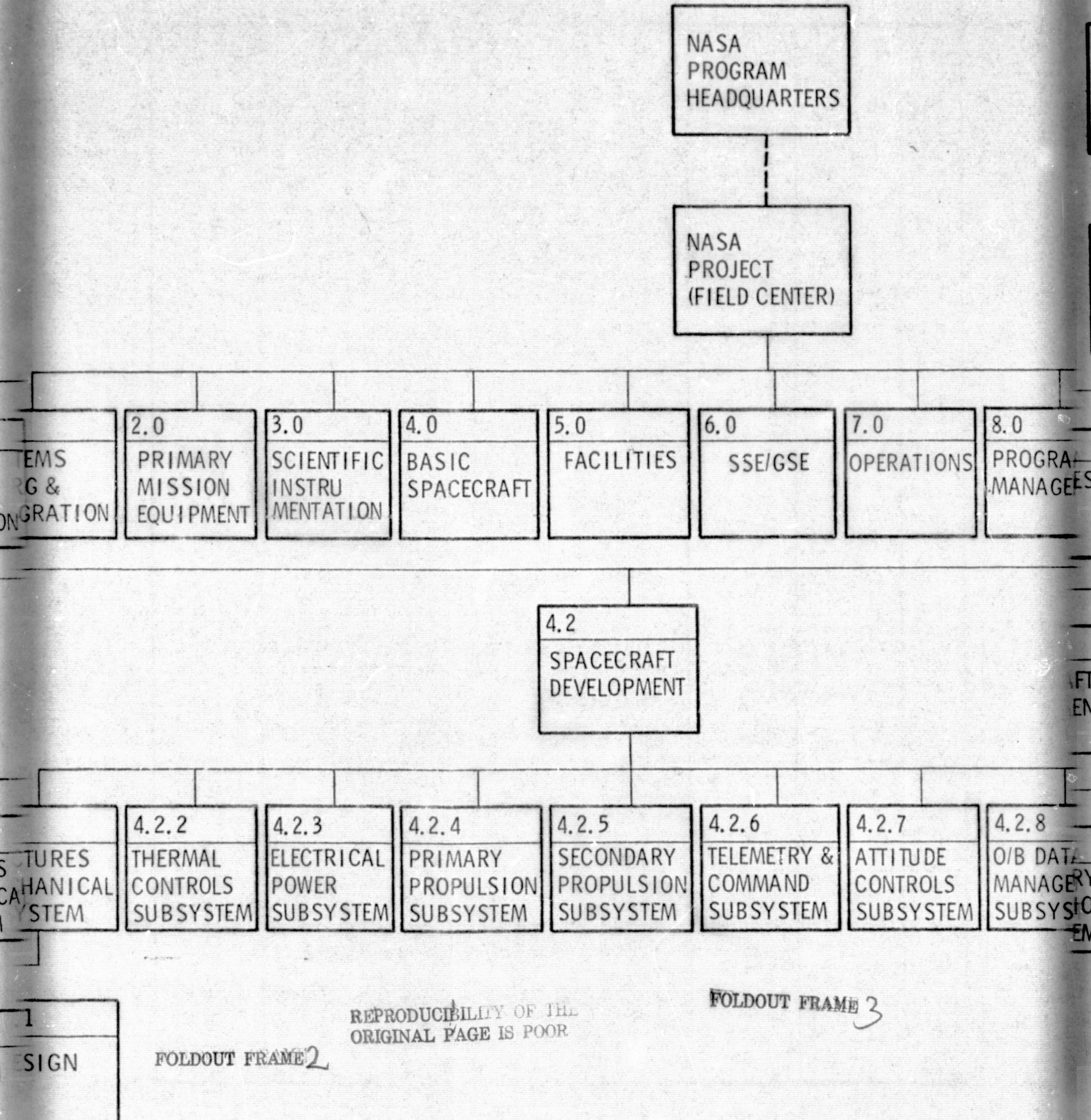
The WBS element arrangement concepts shown in Figures 2-5 and 2-6 allows tracking and reporting of costs at the component level, in addition to preserving the NASA practice of summarizing costs at the subsystem level.

The arrangment also allows direct labor costs to be summed readily, and reported not only by functional division of labor, but also as a separate total for all labor. Presenting and reporting labor costs in this manner, is expected to provide NASA with a set of improved labor cost data. Such a data set can be used to evaluate the cost impacts of low cost technical and management practices to be implemented in future spacecraft projects.

The key to successful standardized work-package development, and implementation, is the constraint to some manageable number, of the total number of end-items and work tasks which are to be tracked, and reported. It was impossible within the time constraints of this study, to complete the trade-off analyses



FOLDOUT FRAME 1



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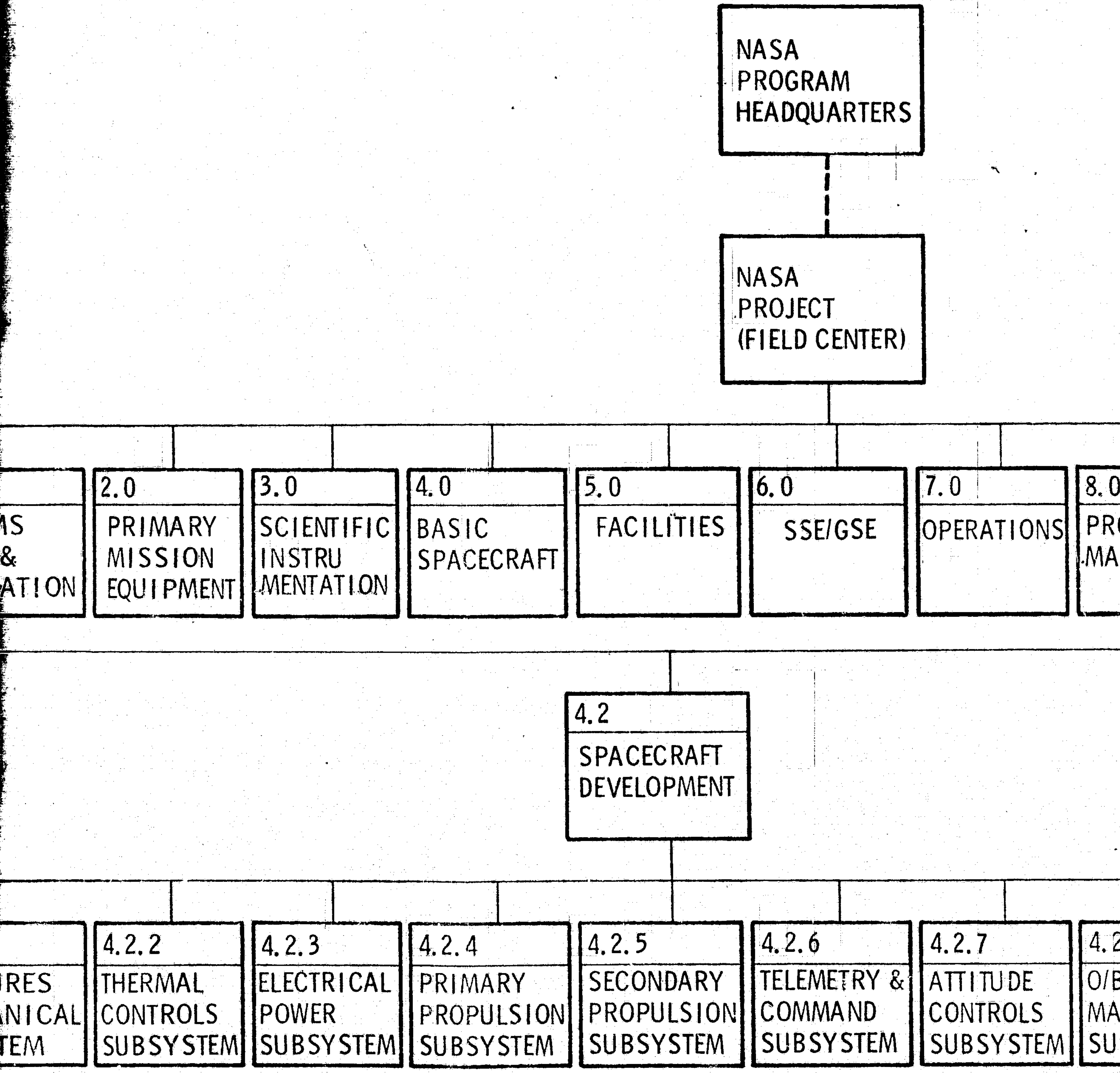
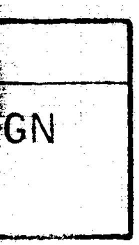

NASA PROGRAM HEADQUARTERS
NASA PROJECT (FIELD CENTER)
MS & ATION
2.0 PRIMARY MISSION EQUIPMENT
3.0 SCIENTIFIC INSTRUMENTATION
4.0 BASIC SPACECRAFT
5.0 FACILITIES
6.0 SSE/GSE
7.0 OPERATIONS
8.0 PR MA
4.2 SPACECRAFT DEVELOPMENT
RES NICAL TEM
4.2.2 THERMAL CONTROLS SUBSYSTEM
4.2.3 ELECTRICAL POWER SUBSYSTEM
4.2.4 PRIMARY PROPULSION SUBSYSTEM
4.2.5 SECONDARY PROPULSION SUBSYSTEM
4.2.6 TELEMETRY & COMMAND SUBSYSTEM
4.2.7 ATTITUDE CONTROLS SUBSYSTEM
4.2 O/B MA SU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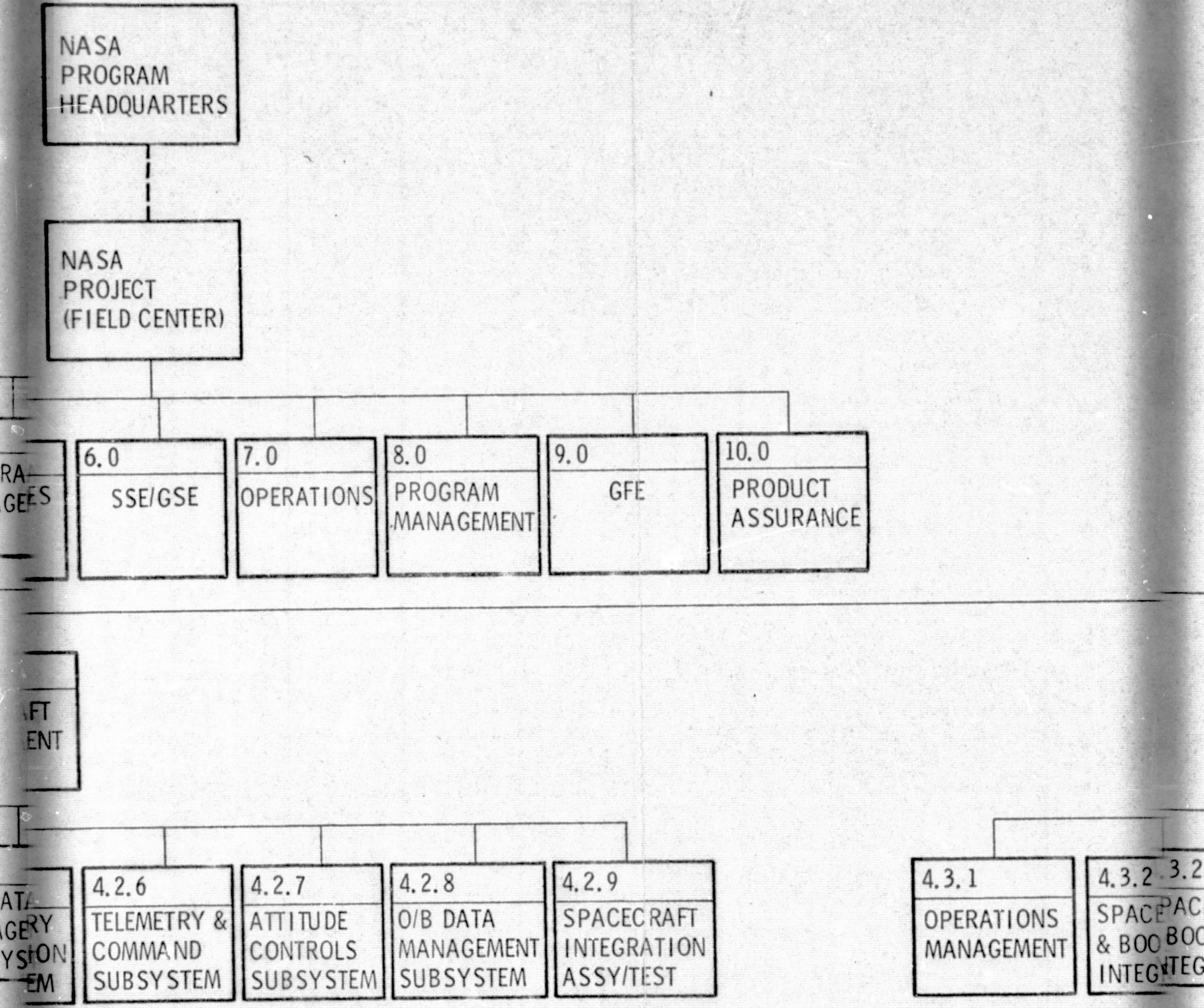

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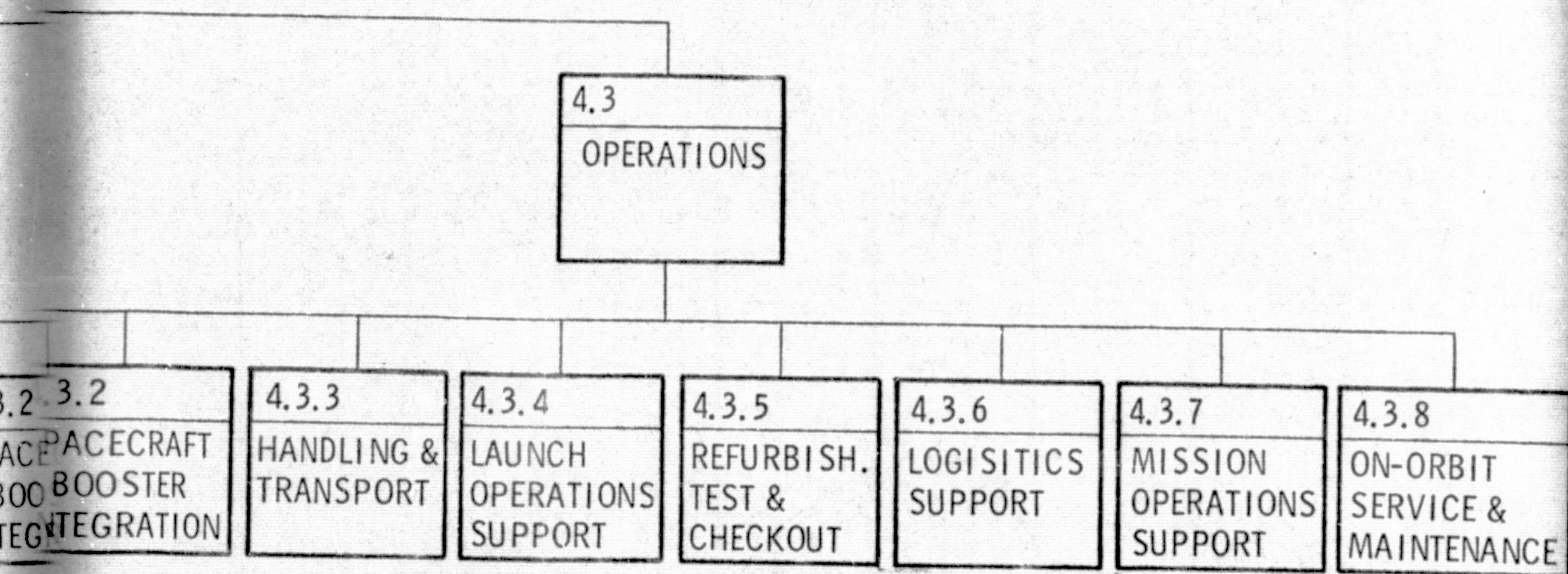

Conceptual Work Breakdown Structure
Total Program Level
Figure 2-4

4.2.1 STRUCTURES & MECHANICAL SUBSYSTEM

- COMPONENTS
- TEST ARTICLES
- MODELS & SIMULATION
- SPECIAL TEST EQUIPT
- GROUND SUPPT EQUIPT
- FLIGHT SUPPT EQUIPT
- TOOLING
- DOCUMENTATION

ENGINEERING

- DES ANAL & TRADE OFFS
- BOARD DESIGN
- ENGINEERING TEST
- SYSTEMS ENGRG & PROG. MGMT SUPPT
- INTERFACE SUPPT
- PROCUREMENT SUPPT
- MEETINGS & PRESENTATIONS
- SPEC ANALYSIS

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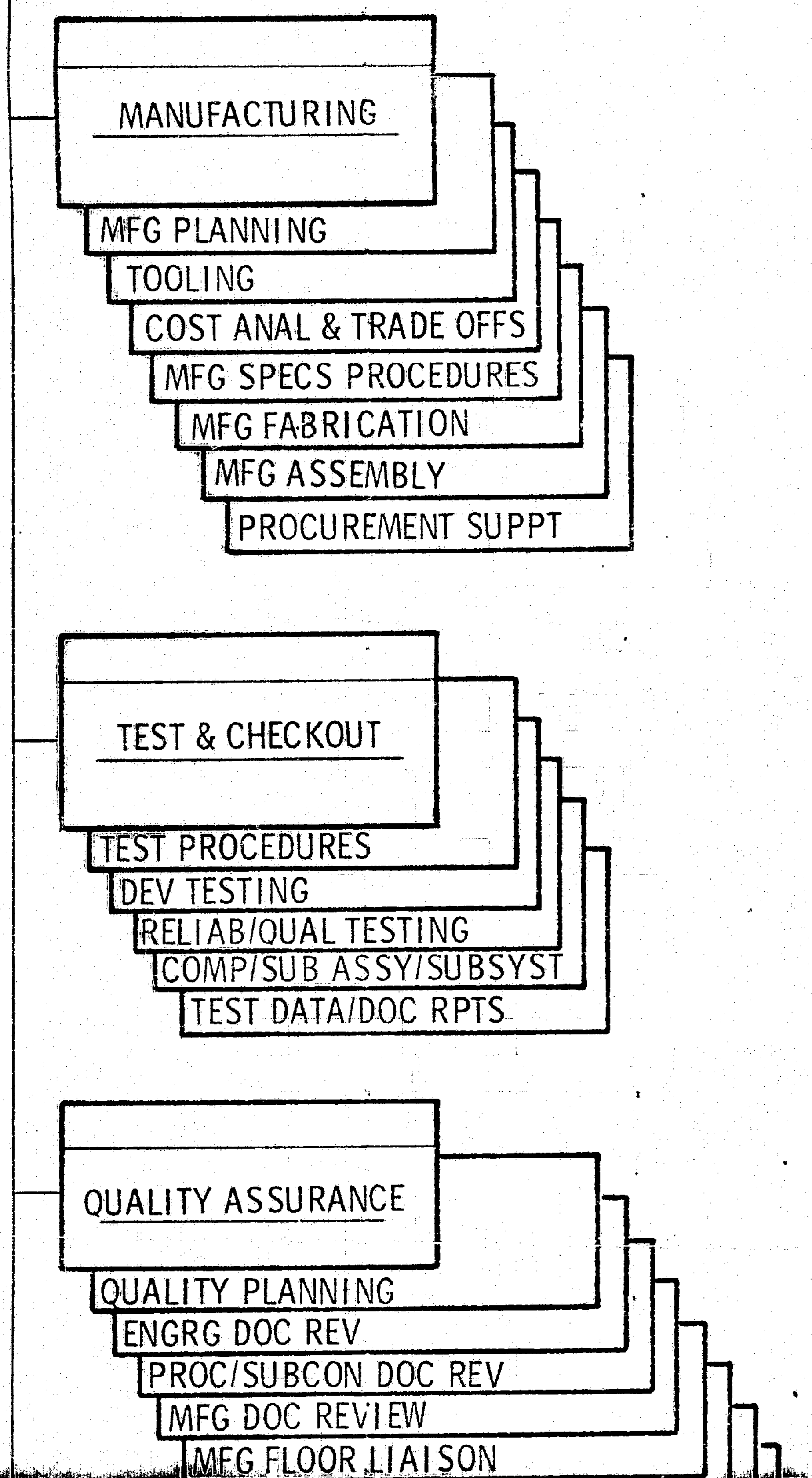

- TEST & CHECKOUT
  - TEST PROCEDURES
  - DEV TESTING
  - RELIAB/QUAL TESTING
  - COMP/SUB ASSY/SUBSYST
  - TEST DATA/DOC RPTS

- QUALITY ASSURANCE
  - QUALITY PLANNING
  - ENGRG DOC REV
  - PROC/SUBCON DOC REV
  - MFG DOC REVIEW
  - MFG FLOOR LIAISON
  - MRB/CORRECT ACTION
  - RECG INSPECTION
  - FAB/ASSY/PROCESS INSPECTION
  - TEST & ACCEPT. INSPECTION
  - TOOLING INSPECTION
  - SUPPL/SUBCON INSPECTION
  - QUAL/INSP RECORDS MAINT.

- RELIABILITY
  - ENGRG DOC REV/ANAL
  - REL/QUAL TEST DATA ANALYSIS
  - PARTS APPLICATION/CONTROL
  - FAILURE ANAL/DIAG CORRECTIVE ACTION
  - PROCUREMENT SUPPORT

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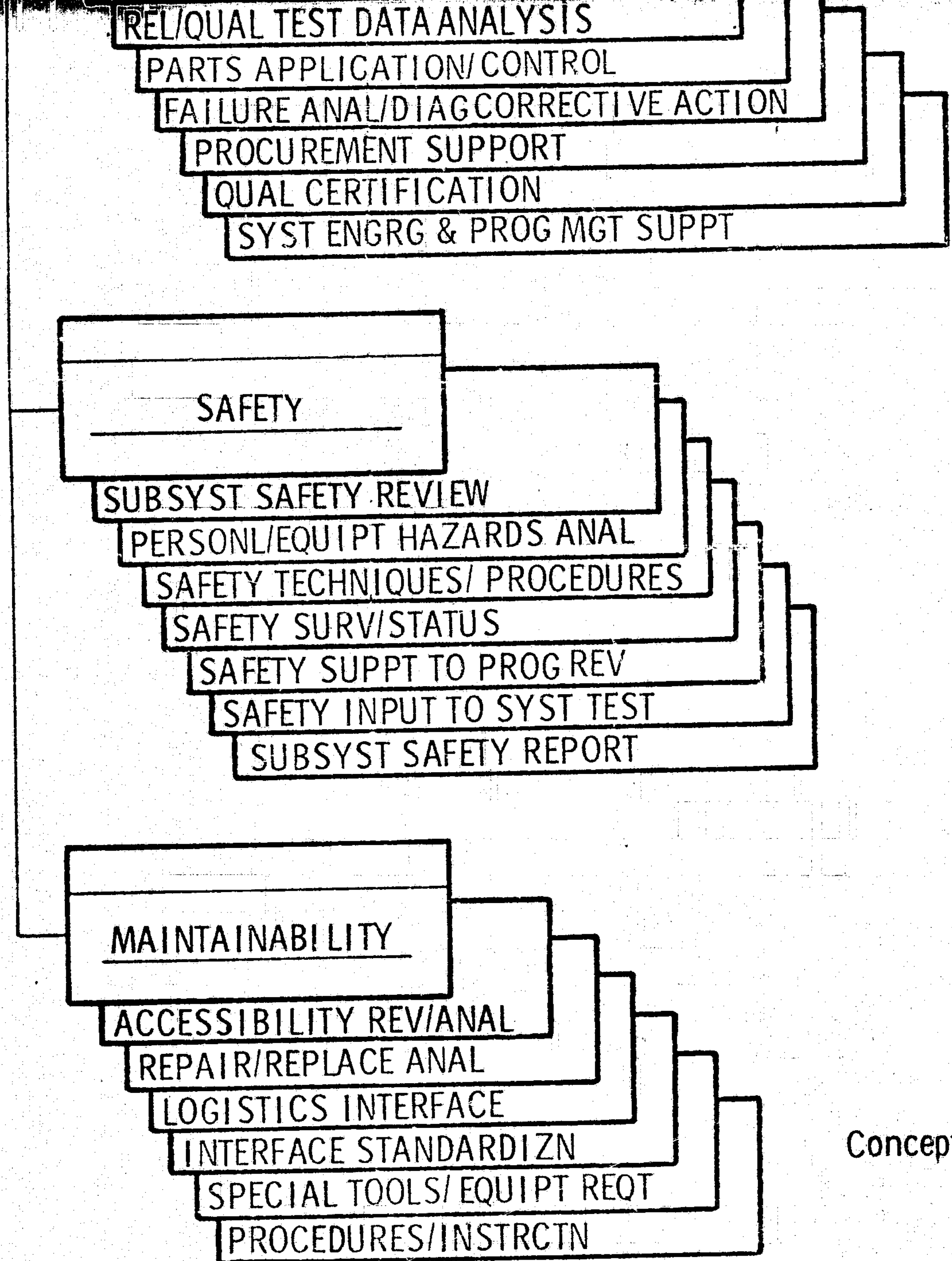

Conceptual Work Breakdown Structure
Subsystem Level
Figure 2-5

FOLDOUT FRAME

4.2.9

SPACECRAFT INTEGRATION ASSEMBLY & TEST

- ALL S/S MAJOR FLIGHT COMPONENTS
- ALL TEST ARTICLES
- MODELS/SIMULATORS
- ALL SPEC. TEST EQUIP'T
- ALL GRD SUPPT EQUIPT
- ALL FLT SUPPT EQUIPT
- ALL TOOLING
- ALL S/S DOCUMENTATION

INTEGRATION & ASSEMBLY DESIGN

- INTEGRATION/ASSY DESIGN ANAL
- INTEGRATION PLANS & PROCEDURES
- INTEGRATED DESIGN/ASSY DOCUMENTATION
- ENGRG SUPPT TO MFG & PROCUREMENT
- ENGRG SUPPT TO SYSTEMS TEST
- MASS PROP/CG DATA ANALYSIS
- DESIGN CHG FROM ASSY & TEST ACTIVITIES
- INTEGRATED ASSY/TEST TOOLING DESIGN

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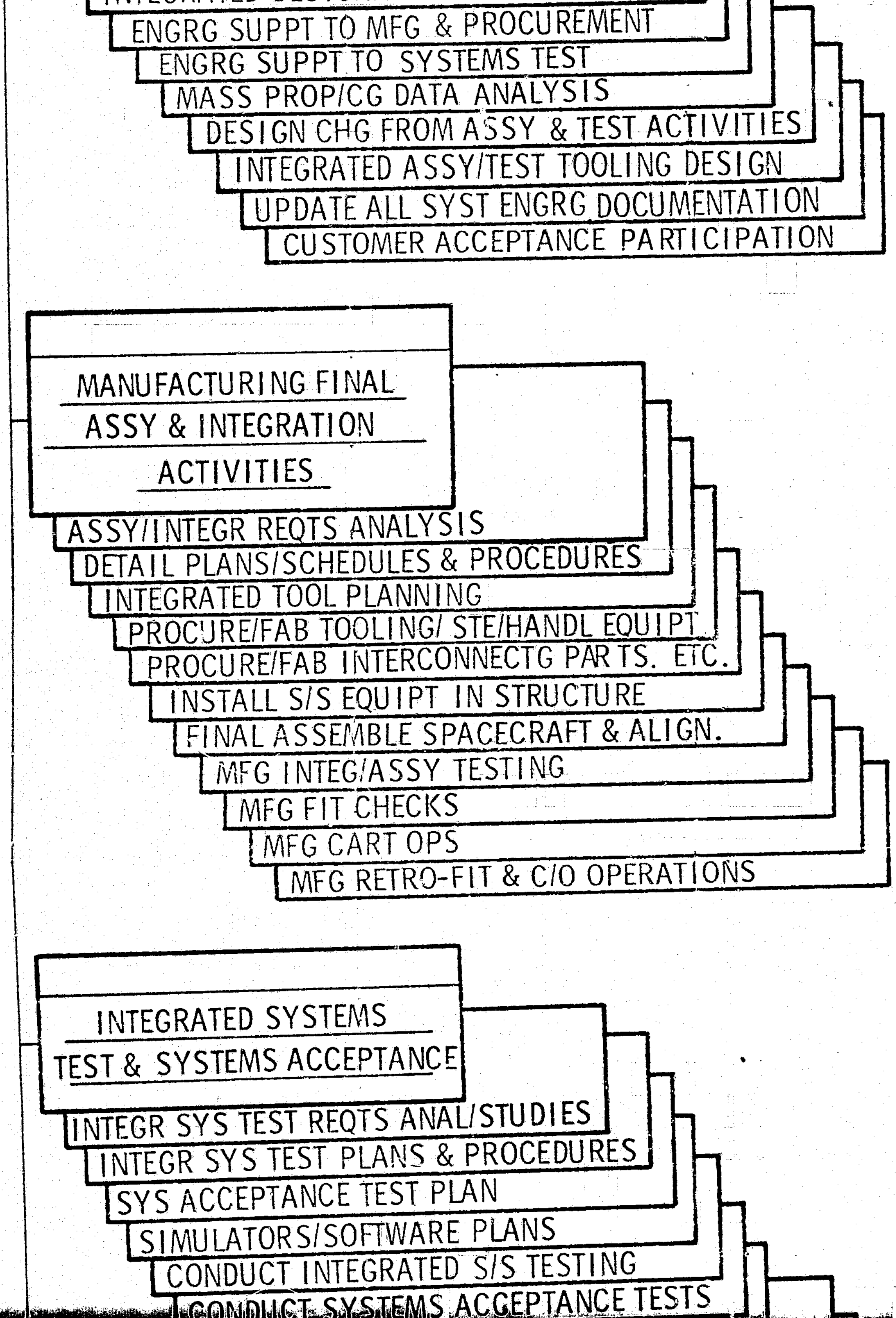
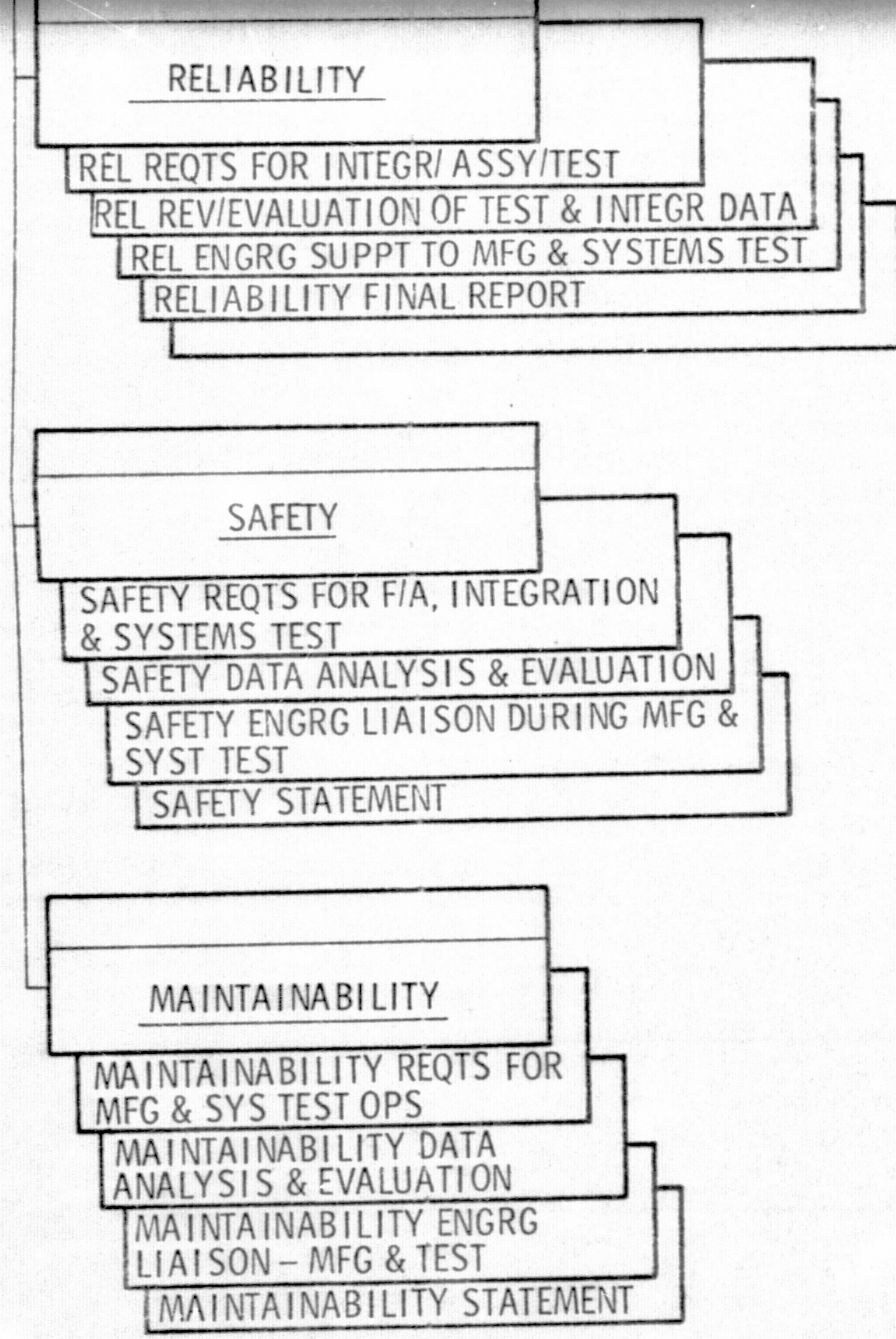




Conceptual Work Breakdown Structure
Subsystem Level
Figure 2-6

necessary to determine this manageable number of end-items, and work tasks; nor has it been possible to prepare exact definitions for them. LMSC is convinced that manageable quantities of end-items/tasks, and standard definitions for them can, and should, be developed. When such are developed they should be acceptable for both program management, and record keeping purposes. Acceptability could be realized by grouping generic families of end-items, services, and work tasks, into suitable categories; applicable to both program management, and record-keeping. To effect this end, considerably more time, and NASA/Contractor interfacing will be required than was available during this study. A feasible approach would be to assign small teams of NASA and contractor personnel to work in parallel, and in support of each other; so that tradeoffs, and incremental decisions needed to establish acceptable work-packages, and their definitions, can be effected in a step-wise manner. During the study it was not possible to determine a "Near-Optimum" quantity of end-items, and work task categories. The difficulty of evolving a manageable number is outlined in the following example:

Example A: Approximately 5,000 cost accounts would be required to accommodate 10 categories of labor under each of the 7 functional divisions of Figure 2-5. Were these 10 categories of labor to be tracked against 10 individual end-items, such as 10 components, in each of the component level end-item categories shown under WBS block 4.2.1; approximately 50,000 - 60,000 cost accounts would be required, should all nine (9) subsystem level blocks be included, (as shown in Figure 2.4). Tracking 50,000 cost accounts exceeds the capability of most CSCSC types of cost reporting system, by an order of magnitude. Program managers, and cost analysts, will not be able to manage, and/or make use of the 20,000 - 25,000 line items of cost that would result.

2.8.3 WBS Dictionaries: All WBS dictionaries reviewed used some method of "Force Grouping" work tasks, and the resultant output descriptions. Specific methods used for historical programs were numerous, and varied, and are unimportant to this discussion. The non standard manner in which "Force Grouping" has been accomplished in NASA programs has precluded commonality of most details in historical records. This lack of commonality has, in turn, prevented formulation of a logical basis for the comparison of costs, and cost effectiveness, between two, or more programs. The concept of standardizing work-

package format, and content, can provide the necessary logical basis for cost comparison among programs, by standardization of the means by which essential "Force Grouping" (and associated definitions) is accomplished for future programs.

REFERENCES

1. Excerpts from NASA FMM 9110. Agency-Wide Coding Structure

2. NHB 9501.2A Procedures for Reporting of Correlated Cost & Performace Data (by Contractors)

3. NHB 23402. OSSA/DART Project Management Information & Control Systems (MICS)

4. MSFC MM 8020.6 Cost/Schedule Performance Criteria (C/SPC) with Implementing Provisions.

5. MSFC/A&PS-CP-S Performance Measurement (C/SPC & TPC) Operations Manual

6. GSFC/HB 7120.1 Handbook for Preparation & Implementation of Work Breakdown Structures

7. NASA/HQ NHB 5610.1 Handbook for Preparation of Work Breakdown Structures

8. MIL-STD-881 Work Breakdown Structures for Defense Materiel Items.

9. MIL-STD-499 Engineering Management.

10. MVM-73 Phase II Project Implementation Plan (JPL/Boeing Corp)

11. MVM-73 Phase II WBS

12. LST - Support Systems Module/Integration Contractor - WBS & WBS Dictionary Drafts & Development History (LMSC versions only)

13. SESP 71-2 WBS (LMSC)

14. SEASAT-A WBS (LMSC)

15. DSCS III Defense Satellite Communications System, WBS/Dictionary. (LMSC)

16. PELSS-Precision Emitter Location Strike System, WBS/Dictionary (LMSC)

17. Selected Descriptions and Users' Guidelines for LMSC Cost & Schedule Performance Reporting System. (CASPER)

Lockheed Missiles & Space Company

ENGINEERING MEMORANDUM

TITLE: STATE-OF-ART SURVEY - QUANTIFICATION OF PROGRAM RISK	EM NO: LCPP-19 REF: DATE: 20 November 1975
AUTHORS: Keith Burbridge Wayne Miller	APPROVAL: D J Hannaford Wayne Miller

62-02 Space Systems Division

Total Pages: 1 thru 19

1. INTRODUCTION

Under Contract NAS W-2752 to NASA/HQ Low Cost Systems Office, LMSC is performing a Low-Cost Program Practices study. Previsous tasks in the study had identified certain low-cost practices which, if implemented by NASA, could result in significant savings in NASA space program costs.

In preliminary review of the low-cost practices with NASA Program Managers, some have evidenced a feeling that implementation of the practices would increase the program risks, particularly those involving mission success. In a separate study task, a qualitative evaluation of risk impact was made for each identified low-cost practice. The results of that task are reported in LMSC Engineering Memo LCPP-15 dated 18 October, 1975, "Assessment of Risk Impact - Low-Cost Program Practices".

Another subtask of the Low Cost Program Practices study, as initially described in the LMSC technical Proposal, LMSC-D426636, paragraph 5.2.6.2, required the identification of the type of data required/desired to allow later quantification of the risk impact.

By agreement with the Low Cost Systems Office, and in consideration of the difficulty experienced in obtaining standardized and more in-depth program cost data via a modified Work Breakdown Structure and cost reporting system; the subtask objective was altered to comprise a survey of contemporary literature on methods of quantifying risk on a program. This engineering memo presents the results of this survey; the information may be useful to NASA as a base for further investigations into risk quantification.

TABLE OF CONTENTS

DEFINITIONS AND GLOSSARY OF TERMS

a. "Risk" - The probability that a planned event will not be attained within the constraints of cost, schedule, or performance by following a specified course of action. Risk is the complement of the cumulative probability:

$$R = 1 - P_r \text{ (Ref 2)}$$

b. Risk Analysis - (1) A process by which uncertainty associated with research, development, and production can be exposed, controlled, or reduced through qualitative and quantitative methodology for purposes of decision making.

(2) A procedure for transforming decision-making-under-uncertainty to decision making-under risk (Ref 1).

c. "Formal Risk Analysis"- Formal means a separate and documented effort, conducted with normally accepted scientific investigative criteria (Ref 4).

d. Performance Risk - The probability that the planned hardware/software mission performance will not be obtained.

e. Cost Risk - The probability that the actual costs of a program will grow and exceed those estimated or targeted for the program. Cost overrun probability.

f. Schedule (or Time) Risk - The probability that the planned schedule will be exceeded or deviated-from, which will result in increasing cost or not meeting a critical schedule milestone(s).

g. "Target Uncertainity"- Associated with defining a need or required operational capability and reducing that need to cost, schedule, and performance goals. (Ref 4)

h. "Technical Uncertainty" - Can it be done at all, for any price: (a) Does the technical solution lie beyond the program time and cost constraints?; (b) Is the solution beyond present technological capabilities? (Ref 2)

i. "Internal Program Uncertainty" - Associated with selecting a particular management approach and carrying it out. (Ref 2).

j. "Process Uncertainty" - Derived from influences external to the program itself. Includes interservice rivalry, national policy, budgeting considerations, Congressional activity. (Ref 4)

k. PERT (Program Evaluation Review Technique) - A network analysis system, originated for the Polaris program, which comprises graphical time-based representation of prgram principal activities and incremental events with interrelationships among events shown by a network of interconnecting lines. Used for showing schedule impacts throughout the program of delays in accomplishment of any one (or more) specific incremental activity. (Ref 1,3)

l. RISCA (Risk Information and Cost Analysis) - A network analyzer computer routine more sophisticated than PERT. Allows simultaneous analysis of time and cost. (Ref 1,3)

m. VERT (Venture Evaluation and Review Technique) - Has all RISCA features plus more flexible types of node logic. Includes a performance variable. Permits several types of functional relationships between/among Time, Cost, Performance variables. (Ref 1).

1. SUMMARY

1.1 General Discussion of Available Literature

Listed in Section 5, "References", are many documents which appear to have either a direct or indirect bearing on quantification of risk. It is believed that these documents represent a valid cross-section of the state-of-the-art. Principle reference only were selected from our local LMSC library and reviewed and excerpts taken to highlight the most recent information available. The selected references were References (1), (2), and (3). A number of other referenced documents are in our library but were not reviewed again for this subtask effort. Reference (39)was obtained informally recently from the Huntsville office of the Planning Research Corp.

Most of the data relate to DOD systems requirements for risk assessment/analysis. The best general reference document appears to Capt Herbert Bevelhymer's thesis paper, Ref (1).

1.2 General Observations About Quantifying Program Risk

a. Historical Data Related to Economic Risk

The majority of historical documents on quantitative risk analysis relate to calculating the risk of investment of dollars into new-business ventures or the probability involved with human life expectancy such as insurance actuarial tables. Some of the statistics are based upon estimates; however, most are based upon fairly large amounts or quantities of actual statistics which have been consolidated and analyzed.

These data are more-or-less readily available in text books on economic risk and probabilities. These general references are not included herein.

b. Most Program Risk Analysis Directed Toward Analysis of On-Going Programs

In the several documents reviewed (DOD sources), the principal emphasis was on the analysis of on-going programs. The objective was to assess the trend of program toward lesser risk or greater risk by review of actual program data (costs, schedule, and technical accomplishment), versus initial estimates or program targets. Also, some analysis was devoted to comparative risks when judging whether a change should be implemented into an on-going program (usually analysis of cost/time alteration as a result of change).

c. Risk Tradeoffs in Terms of Hardware Reliability

Some historical data treat technical or performance risk in terms of reliability of the hardware. The risk is defined as $1 - P_r$ where P_r equals the reliability or probability of success. For this type of analysis, actual data (such as historical test results, failure rates, or similar) must be available to identify the analysis as statistically valid. Otherwise, the analysis is based upon subjective data,or estimates.

d. Little Data on Performance Risk

Most of the data available deals principally with cost and schedule risk parameters. Because of the large variations in parameters which may be used to derive performance risk, most have avoided looking into this latter area in any depth. Ref (39) is an exception; however, the analytical approach therein is hypothetical in nature and is based on personal and subjective estimates. The purist statitician might dispute the general approaches taken in the analysis on the basis that actual program data were not used.

e. Consideration of Risk Before the Program is Started and Applicability to Low-Cost Practice Assessment

Throughout this assessment of state-of-the-art on program risk, we were looking for two things:

(1) Risk analysis methodology, used to analyze an on-going program status, which might be modified to analyze a new program not yet undertaken

(2) General risk analysis approaches which might be adapted to include analysis of low-cost practice impacts

2. GENERAL CONCLUSIONS OF THE SURVEY

2.1 It appears that there is no directly applicable existing methodology which can be applied to quantify the schedule time, cost, and performance risks of a new (unstarted) program.

2.2 To assess risks in a quantitative manner, particularly performance risk, with a reasonable degree of statistical validity, sets of data are required:

(1) A fairly well-defined design of the proposed new-program hardware.

(2) A good estimate on the various elements of the new program, with detailed estimates down through the major component level of the Work Breakdown Structure.

(3) Historical data from previous programs, both "normal" and "low-cost". These data as a minimum should include:

a. Performance Requirements, at vehicle, subsystem, and component level.

b. Schedule Data, preferably in a PERT-type or VERT-type network.

c. Cost Data, at vehicle, subsystem, and component level.

These data should be available on a "standardized" basis so that summations, means, and deviations can be readily determined and used as a comparison base for new-program risks.

2.3 The availability of historical data on actual low-cost programs (as outlined above in 2.2(3) seems to be almost totally lacking. If quantification of risk is to be pursued, and based upon historical data, it appears that program data must be collected on a standardized and more complete basis than is being accomplished currently.

3. REQUIREMENTS FOR QUANTITATIVE ANALYSIS OF LOW-COST PRACTICES

3.1 Historical Data Required for Formal Statistical Analysis

If more than a subjective estimate is required for new-program risk analysis, actual data from previous programs is essential. Specific and usable data on "low-cost" programs is probably not available at this time. If "normal" practices, and their attendant typical cost, time, and performance parameters, are used as the only comparative historical baseline; all new programs analyzed will possibly show a statistical increase in risk if their equivalent parameters are the result

of low-cost practice application. For example, deviations from the "normal" practice time, cost, or performance values could be interpreted (analytically) as increase in risk.

It is therefore necessary to create comparative a set of actual data on "low-cost" programs, particularly where mission performance has been acceptable.

3.2 Time Variants or Schedule Risk

a. Analysis of schedule risks requires a PERT-type schedule network on each project to be evaluated. Historical projects require similar sehedule/time representation (and most NASA programs have not used PERT-type networks). Assuming both new-program and historical-program data can be made available, and assuming some degree of standardization to allow easier comparison, element-by-element; similarity ratings can be derived.

b. The new-program elements could be compared with the baseline set (historical) using either manual or automated scanning techniques. Deviations from the historical norm would be rated as a degree of risk.

c. The baseline reference times would require subdivisions, probably to the component level; for example, time to design a specific major component or a group of subsystem components.

A problem foreseen with schedule network comparisons and summing to the total time is the degree to which explicit elements of work or activities may overlap. Figure 1 shows a hypothetical case wherein the design of compoents A, B, and C are identical for all three cases, but the overall schedule time for the subsystem group of components is quite different.

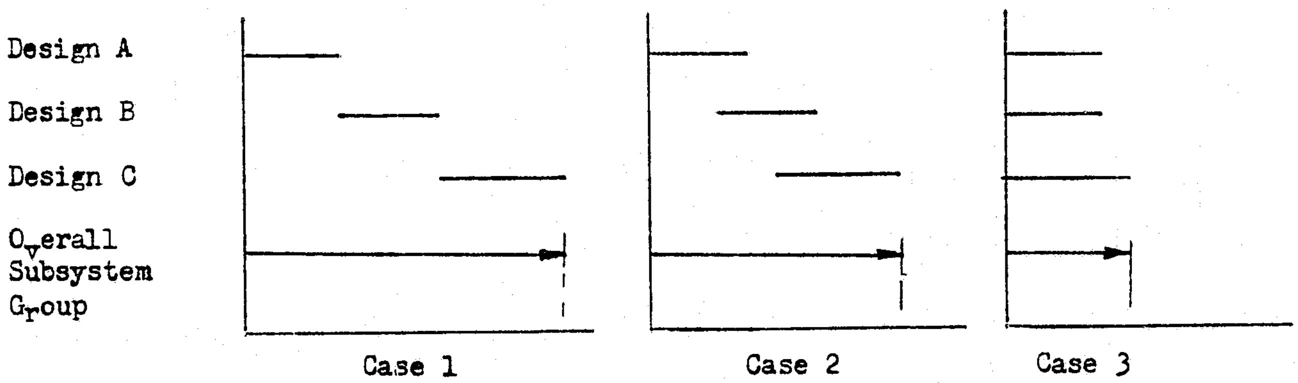


Figure 1 - Three Cases of Schedule Summation Variation

3.3 Cost Variants or Cost Risk

Analysis of costs requires a common base of comparison. Because of the wide variation of subsystems performing a similar function, it appears that the cost breakouts to the component level is required to allow comparison of costs with any degree of validity. Summing of costs could be accomplished at subsystem and vehicle level (with added cost elements for integration, program management, etc.).

Assuming that cost data were available at the component level on both historical and new programs, complexity, operational environment, MTBF, and other factors

could be applied and comparisons of cost derived. The deviation of the new-program component cost from the baseline historical could be a measure of cost risk (probable cost overrun or underrun).

A requirement for collection of costs on a uniform basis must be applied; a standardized cost recording system appears mandatory. Inclusion or exclusion of items such as component testing cost or component test equipment or tooling costs could cause major variations (frequently tooling, test equipment, and testing costs are summed in subsystem or general cost blocks and not included in component summed cost).

There are other cost-impacting parameters (such as inflation, labor-rate variations) which are non-risk-related and must be handled as separately-normalized entities.

3.4 Performance Risk

This risk characteristic is the most difficult of the three risk areas to be quantified in terms which will allow comparison of a baseline (historical) with a new-program requirement.

Performance characteristics have not yet been standardized; also, the actual performance recorded on historical program is frequently not well-defined in terms of the initial mission requirements. Many of the requirements have been met partially, but apparently adequate enough to rate the program as successful.

Here again, it would seem advisable to define performance requirements at three levels: vehicle, subsystem, and component. Hopefully, a direct relationship could be established for each performance parameter at all three levels. For example, pointing accuracy could be related to a Star Tracker (component), the Navigation Guidance & Control Subsystem, and at the total vehicle level.

It appears that assignment of risk to a level of performance might have to be on a subjective estimate basis, using both historical "accomplished" performance and new-technology probabilities. In some cases, where historical performance data were actual, based upon tests and operational results (rather than upon "a priori" estimates); the achieved reliability could possibly be used as a measure of the performance risk. In any case, a fairly detailed design definition of the new-program component would be needed to allow a rigorous statistical performance risk assessment.

3.5 Combined Time/Cost/Performance Risk

Relationships can be established more or less readily between time and cost. Relationship of performance and cost is more difficult. There is not necessarily a discernible statistical relationship between performance and time. Interrelating all three risk parameters is necessary to obtain and overall program risk; this is theoretically possible but will require specific development.

4. HIGHLIGHTS OF LITERATURE REVIEWED ON QUANTITATIVE RISK ANALYSIS/ASSESSMENT

4.1 General Approach to Quantitative Risk Analysis (Ref 1)

4.1.1 Objectives

a. Devise a technique to use, for quantitative time/cost risk assessment, data that a program office normally receives from a contractor under CSCS reporting requirements.

b. Reduce the high cost of currently-accepted quantitative risk assessment (gathering of special data and lengthy analysis).

c. Methodology directed toward continuously assessing risk during development phase of a weapon system.

4.1.2 Summary of Approach

a. Formal risk analysis has become a required part of the weapons acquisition process since 1969.

b. Many methods of quantitative risk assessment require extensive data collection solely for risk purposes. Frequent assessments therefore become costly.

c. Ref (1) proposes a risk assessment methodology that uses contractor-reported data extracted from the standard Cost Performance Report and the Schedule Status Report.

d. A graphical network of a project can be constructre using the symbology and logic available with the Venture Evaluation and Review Technique (VERT) computer routine. Each network arc can be made to correspond with a contract WBS element.

e. The parameters of each arc's time and cost distribution can be determined using the contractor's monthly revised estimates for WBS element costs and completion dates.

f. A test application on a weapons system currently in full-scale development was conducted. The test results were inconclusive but did show promise for further application of the methodology.

4.1.3 Hypothetical Risk Profile

Figure 2 shows a hypothetical approach to pictorially showing risk. A probability density function (pdf) is graphed as a Beta distribution, converted to a cumulative distribution function (cdf), and then the complement of the cdf is graphed as the risk profile. The risk profile provides an indication of quantified uncertainty limits.

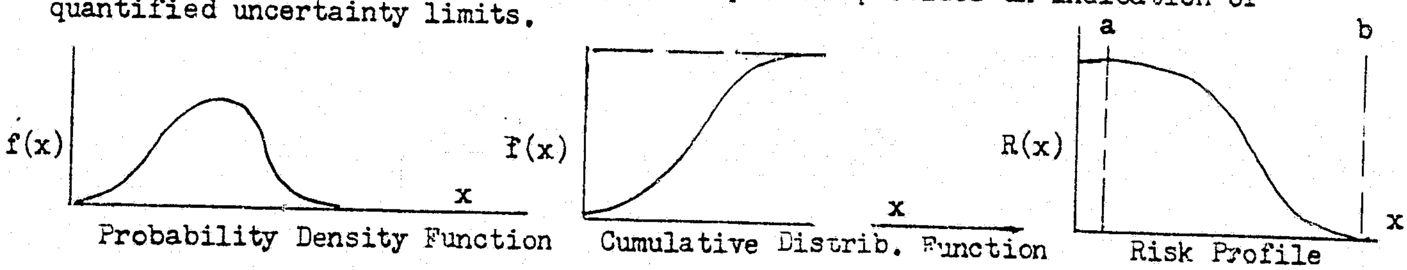


Figure 2 - Risk Profile

4.1.4 Emphasis on Network Simulation

Many techniques for quantitative analysis have been proposed; the most extensive treatment is given to various network simulation approaches. Simulation techniques are an advantage when actual data are not available, and permits conditional probabilities to be used.

4.1.5 Subjective Estimation Required.

For PERT and other network techniques, the mean and variance of the individual distributions must be estimated to be quantitatively useful. Two serious obstacles exist to estimating for a development project:

a. Usually there are no data from which quantities can be estimated; thus estimates must be subjective.

b. It is very difficult to form a subjective estimate of the activity time.

4.2 Simulation Methods in Risk Analysis

4.2.1 General Applications of Simulation Analysis (Ref 3)

a. Difficulty associated with sensivity analysis was chiefly that no estimate of likelihood of occurrence of various system costs could be obtained. Monte Carlo methods (among others) can be employed to generate the likelihood profile of total system costs where it is possible to estimate the profile for individual cost factors.

b. Time to project completion, cost of project, and performance of resulting systems usually depend upon a number of input random variables. If one is able to impute probability distribution to each input variable, the problem still remains to find the output distribution. Figure 3 is a hypothetical graphical illustration of the general case wherein: input variables are costs associated with (1) physical subsystems and (2) changes in system configuration (changes in requirements).

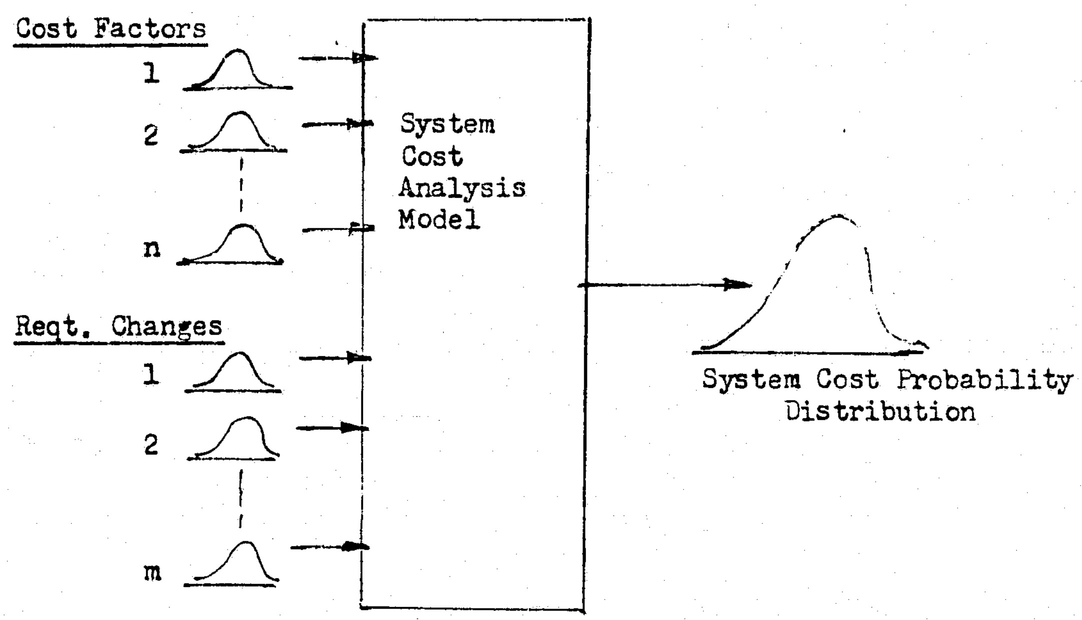


Figure 3 - Graphical Representation of System Cost Risk Analysis

4.2.2 Some Quantitative Measures of Uncertainty (Ref 3)

a. Probability of meeting or failing to meet specific goals of project performance, cost, or completion time.

b. Expected value of a slippage of any of the time, cost, or performance factors.

c. Variance or standard deviations of time, cost, performance.

4.2.3 Monte Carlo Simulation Using PERT

a. Monte Carlo simulations can be applied to PERT networks. Each trial of the simulation yields a "realization" of the network with a fixed value for each of the activity durations. Project duration equals the sum of the times on the critical path. After simulation has been conducted a large number of trials (10,000 not uncommon), the estimated mean project duration is computed as the arithmetic average of simulated durations for all trials.

b. Each arc time (between network nodes) has a pessimistic, most-likely, and optimistic estimate. A 200-activity network and 10,000 trials would require 20 minutes on an IBM 7094 computer, 2.5 minutes on an 1108. PERT can be extremely time-consuming for large networks; nevertheless, outlook for the future of planning R&D projects includes much more in the way of computer-assisted PERT simulations than exists today (1971).

c. A typical output of the simulation run may show a distribution as illustrated in Figure 4.

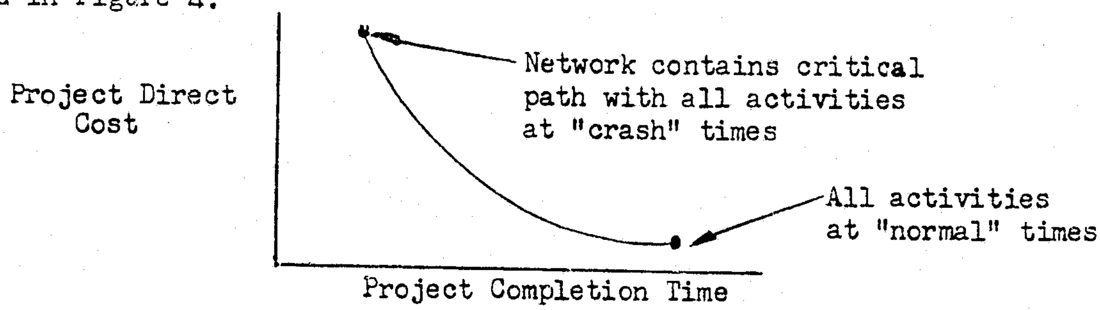


Figure 4 - Project Cost vs Project Time

4.2.3 Use of RISCA Computer Routine for Simulation

a. (Ref 1) RISCA (Risk Information and Cost Analysis) is a network analyzer computer routine more sophisticated than PERT;

(1) Allows simultaneous analysis of time and cost. Treats an activity cost as a linear function of activity (may be unacceptable in many applications; costs may require separate processing).

(2) Incorporates Monte Carlo processing and provides output time and cost distributions for every terminal node of the network.

(3) Permits greater flexibility in characterizing activity probability distribution; it does not limit inputs to Beta distributions.

b. (Ref 3) A user-interactive computer program, RISCA, that facilitates analysis of systems that are represented by a general class of network structures can be used. It provides the capability to construct desirable net representation of this system. Then it can run Monte Carlo simulations of the network.

Based upon the output statistics from a run (for example, time,cost, and frequency distributions), the user can modify his net to evaluate system design.

4.2.5 Use of VERT Simulation

4.2.5.1 Bevelhymer's Approach (Ref 1)

a. VERT (Venture Evaluation and Review Technique) incorporates more flexible types of node logic than RISCA. Permits a more accurate modelling of real-world situations.

b. VERT also includes a performance variable; the variable can be selected by the user. Permits several types of functional relationships between/among time, cost, performance.

c. Different critical path criteria, other than time, can be selected. A cost critical path or a critical path determined by weighted comparison of 2 or 3 variables can be specified.

d. VERT can discount costs, adding present-value cost dimension.

e. One possible difficulty with VERT: the performance measure specified must be additive (just like time and cost) from node to node on the network. Development projects, consisting of aggregation of subsystems and standard performance parameters among subsystems, are not homogenous. For example, thrust and specific fuel consumption for propulsion subsystem cannot be added diredtly to drag and weight for an airplane subsystem.

4.2.5.2 Attempt to Use VERT on A-10 Aircraft Program (Ref 2)

a. Methodology

(1) Consisted of constructing a realistic summary network of the A-10 Full Scale Development Project up to the time of 2nd DT&E aircraft mating to the 30 mm gun.

(2) The network was based upon WBS elements to afford comparison with the Cost Performance Report data.

(3) Data were based on principles of subjective probability, estimates to be obtained from contractor personnel.

(4) Estimates were to be fitted to a triangular distribution to obtain the required time and cost probability density functions for each activity in the network.

(5) The risk profiles for individual activities were to be computed and aggregated using the VERT simulation routine to obtain overall risk profiles for schedule and cost.

b. Major Problems

(1) Unable to find experts within contractor organization who could provide aggregate time and cost estimates for the entire WBS activity. Crux of problem lies in the relationship between the WBS and the functional structure.

(2) In order to determine how far along one activity must be before another can begin, one would have to network the project at the work package

level. There are 3000 work packages in the A-10 airaraft structure program alone.

(3) Biased time/cost estimates from the functional managers was also a problem.

c. Results

Unable to construct a WBS-based network that was consistent with the requirements of the basic methodology. The methodology was abandoned as impractical.

4.2.6 Range of Estimates Required (Ref 2)

The major data premise for risk analysis is that cost, time, and performance parameters are realization of random variables. One must obtain a range of estimates for each estimate.

4.2.7 Cost and Time Summations (Ref 2)

a. All arc costs on the network are summed for total system cost.

b. Only those times on the network critical paths or near-critical paths contribute to the total system development time.

4.2.8 Difficulty With Performance Parameters (Ref 2)

Performance risk is the most ill-defined and perplexing parameter. The many factors that could be used in one program depend on weapons, threat, mission, and other parameters.

Performance parameters are not homogenous and hence do not readily lend themselves to an additive scheme like network simulation. For example, the A-10 aircraft specified general performance requirements as high payload capacity, small turn radius, long loiter time. There are no mathematical transformations which allow additive accumulation of a performance parameter that simultansously represents ordnance capacity, radial acceleration, and time-on-target achievement levels.

4.3 Techniques for Determination of Distribution of Performance Factors (Ref 3)

a. Analytical methods may be difficult or impossible.

b. Numerical methods range from (1) numerical integration to (2) probability models based upon discrete approximations of continuous distributions.

c. Simulation probably will require large quantities of runs to assure significance.

d. Quantification of the likelihood of meeting the technical objectives may be exceedingly difficult; some cases may be relatively simple. Some technical objectives are of an all or nothing variety; others represent cases where some departure from the specification requirement is not catastrophic (attention was focused upon the latter case).

e. Performance variables are functionally related to: (1) design variables, (2) operating variables, and (3) environmental variables. For example, payload of a helicopter is affected by:

- o Air density - environmental variable
- o Rotor lift coeff. - design variable
- o Operating weight - operational variable

f. Experts were asked to estimate performance characteristics and to approximate distribution profile; the distribution profile was cataloged as uniform, triangular, or constant (See Figure 5).

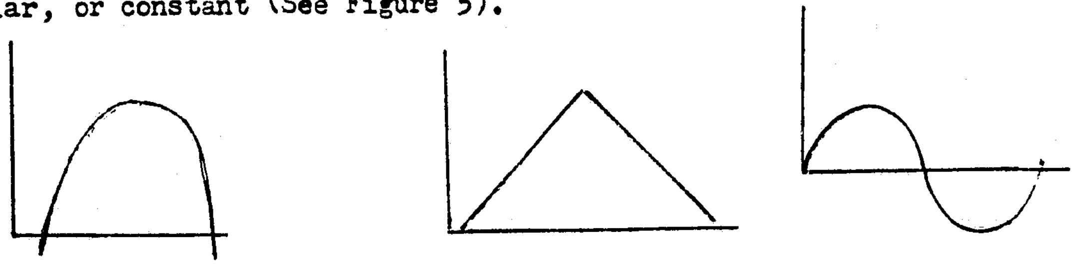


Figure 5 - Distribution Profiles of Performance Characteristics

g. The next step included the determination of joint probability that all performance specifications would be exceeded. In the case of the helicopter rotor problem, the Risk Analysis Team (RAT) concluded that the program risk was very high (a low probability, 0.425 to 0.125, that performance requirements would be exceeded).

4.4 Use of Actual Data in Lieu of Estimate

a. Literature on applied risk analysis is highly weighted in favor of subjective assessment techniques to provide the necessary input probability distributions for a network model. If a methodology could be developed to use data currently provided by a contractor to estimate these inputs, it could afford an inexpensive method for assessing risk on a continuing basis.

b. Collection of monthly WBS completion costs and time estimates can each be considered an independent, random sample whose size is increased by one each time a monthly report is received from the contractor.

c. The range values for each WBS element must be determined for time and cost. Although not normally reported, data values could be provided at far lower cost than required currently for extensive subjective assessments.

4.5 Sample Risk Profiles from Test Case Runs (Ref 1)

Figure 6 shows sample risk profiles determined from test runs. They indicate the essential variations in profile resulting from sensitivity checks wherein the inputs are varied.

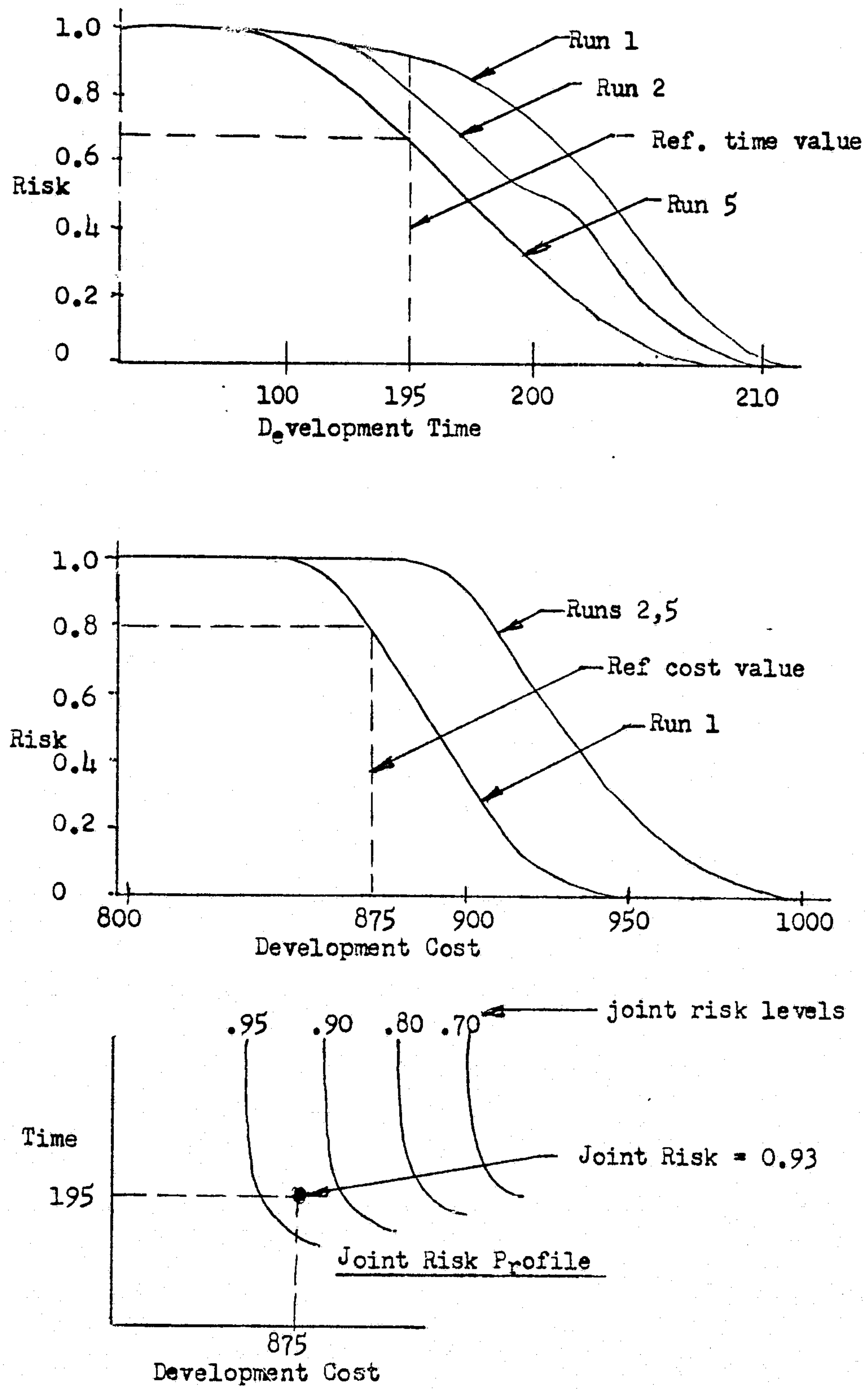
4.6 Assessing Contractor Performance (Quantitative Risk Assessment) (Ref 2)

4.6.1 Objectives

Determine feasibility of a formal risk assessment methodology using subjectively-based probabilistic estimates as inputs for a computerized network simulation; apply the methodology to actual weapon system acquisition program environment, in this case, to the A-10 aircraft structure. This provides a method for forecasting contractor's performance.

The incentives for research study were notorious examples of cost overrun, schedule slippage, and performance degradation within major weapon system acquisition. In general, answer the question, "How do we go about assessing program risk?"

Figure 6 - Risk Profiles



4.6.2 Observations

a. Bevelhymer's work (Ref 1) is the only actual test case using network analysis; other have advocated it and produced hypothetical examples (Ref 23,33,34) While not a network-based technique, Thomas (Ref 35) has successfully employed an accumulatiive approach using subjective inputs and producing probabilistic estimates of total risk in bidder's replies to RFP.

b. The technique which offers the most promise in quantitative risk assessment is a versatile, simulative approach using group assessment techniques, subjective probability, technological forecasting, cost estimating, and other sources of input.

c. Preponderance of risk analysis literature suggests use of subjectively obtained data; Bevelhymer (Ref 1) initially attempted simulation using data from contractor documents. He could not obtain such information solely from contractor data and was forced to resort to subjective estimates for range end-points for the cost variables.

d. Most works on risk analysis are primarily directed toward recognition and assessment of technical uncertainties (Ref 31,33,36).

e. Because of the difficulty of identifying additive performance parameters, the performance aspect of risk assessment was disregarded and emphasis placed upon cost and time parameters.

4.7 Examples of Performance Risk Analysis (Ref 3)
The appendices of Ref (3) show examples of risk analysis:

a. Appendix 1 - Risk Analysis of Armored Vehicle-Launched Bridge
Evaluation of several alternate proposals and project stagings for a 90-foot segmented extendable bridge (was 50 feet) deployed by a tank.

b. Appendix 2 - Micon-Air Defense Missile Warhead/Fuze Subsystem Performance Risk Analysis
Assessment of probability of kill, mainly centered on fuze reliability.

c. Appendix 3 - Helicopter Performance Risk Analysis (Hypothetical Example)
Evaluation of likelihood of meeting performance specification requirements in light of serious mid-program trouble: serious dynamic instability problem at elevated speeds (delaying R&D efforts). Many performance variables; small subset of these included:

- o Maximum forward flight speed
- o Hover altitude
- o Maximum ferry usage
- o Endurance
- o Payload
- o Rate of climb

4.8 Risk Estimating Techniques for Planetary Spacecraft Performance (Ref 39)

a. The modelling was not tailored to use of actual program time, or cost data nor to program simulation techniques. Some of the parametric relationships shown which impact performance are rather interesting. In general, the technique described treats risk as one minue the probability of success (reliability).

b. Presents the results of a small exploratory study on development of a risk model for unmanned planetary mission, the Mars Orbiter/Lander 1973/75.

c. Deals primarily with risks involving:

- o Schedule
- o Number of spacecraft per launch
- o Number of launches
- o Impact of spacecraft sterilization
- o Level of combined system testing

d. Risk was quantified independent of cost. Schedule risk was included as a management risk under mission design.

e. All data were based upon subjective estimates. The model was calibrated using data from the 1964 Mariner IV mission and parametric estimates for the 1973/75 Mars Orbiter/Lander.

f. The mission risk summary was shown as:

$$R_M = 1 - (1 - R_{MD})\,(1 - R_{SBD})\,(1 - R_{CST})\,(1 - R_{SFO})$$

where:

R_{MD} = mission design risk

R_{SBD} = risk for subsystem design/development phase

R_{CST} = combined system testing risk

R_{SFO} = space flight operations risk

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ENGINEERING MEMORANDUM

TITLE: A LOW COST NASA ENGINEERING DRAWINGS AND LISTS SPECIFICATION.	EM NO: LCPP-20 REF: DATE: December 10,1975
AUTHORS: H.K.Burbridge.	APPROVAL: ENGINEERING SYSTEM ENGRG

1.0 Historical Background:

Since 1957 the specification which has controlled the production of engineering drawings and lists procured by the Federal Government of the U.S.A. has been MIL-D-1000. This document was generated for use by the DoD in order that military materiel and capital equipment drawings might be standardized to some degree, reproduced in a large number of legible copies, and used by any given manufacture under Government contract to produce military hardware. In the rapid build-up of the NASA as a Government agency responsible for the manned lunar series of missions, the relatively short interval of less than a decade, precluded development of a drawings and lists specification adequate for the needs of the aerospace industry. MIL-D-1000 was inherited by the NASA, and used to procure drawings. While the specification served as a regulating document, drawings produced under its control have not been low cost, and considerable confusion arises from the interpretation of the specification in terms of its requirements.

1.1 MIL-D-1000; Implementation Difficulties:

Aerospace Contractors attempting to comply with MIL-D-1000 when this document is invoked by their contracts with Government agencies encounter several difficulties. These arise from the fact that MIL-D-1000 can be implemented in any one of three Forms, and in one, or several of 10 categories. Details of forms and categories are as follows:

- o Form 1 requires: Full Military compliance/control
- o Form 2 requires: Partial Military Control
- o Form 3 requires: Drawings to Industry Standards with minimum military controls.

The 10 categories involved are titled as follows, and cover all conceivable types of hardware and hardware service:

A Design Evaluation

B Interface Control

C Service Test

D Logistic Support

E Procurement (identical items)

F Procurement (interchangeable items)

G Installation

H Maintenance

I Government Manufacture

J Interchangeability Control

MIL-D-1000 defines all these categories, and states that the Government will define, and specify, per each procurement from a contractor; the Form(s) and category(ies) under which the drawings are to be prepared.

1.1.1. The Subtier Document Difficulty:

Should a Government agency invoke Form 1 of MIL-D-1000 in procuring engineering drawings and lists, full compliance by a contractor requires that no less than 38 subtier documents must be acquired, scrutinized, and their requirements reflected in the drawings ultimately produced, under any or all categories. Form 2, which has been the usual Form invoked by the NASA imposes by sub-tier, only 12 documents, which alleviates the complexity of drawing production to a degree. Where Form 3 is invoked, only 4 documents are invoked as sub-tier dependancies. This Form, which has the minimum of Government control, requires only that tracing paper of a given standard be used, that documents/drawings be inspected for count, identity and damage, and that the Government's rights to security be observed. The documents/specifications invoked as sub-tier dependancies for the 3 Forms, are listed in Figure 1. As can be seen from this figure, Form 3 gives almost total latitude to the contractor in the preparation of drawings destined for Government use, whereas Form 2 still imposes some of the requirements. The curre[illegible] opinion within the NASA is that Form 1 is too costly, Form 2 still imposes too much control, while Form 3 imposes too little. Problems can arise from the imposition of Form 3 by contractual requirement, since

MIL D 1000 Sp cifications
Dependency Li ting:All tiers

Federal Specs:

UU-P-00561...	Paper,Tracing.	(2)(3)
CCC-C-531 ...	Cloth, Tracing.	(2)

Military Standards:

MIL STD 100A...	ENGINEERING DRAWING PRACTICES (Cost Driver)	(2, portions only)
MIL-STD-143 ...	Order of precedence, specs, stds.	(2)
MIL-STD-9......	Screw Threads	
MIL-STD-12C....	Abbreviations	
MIL-STD-14.....	Architectural Symbols	
MIL-STD-15.....	Electrical Symbols	
MIL-STD-17.....	Mechanical Symbols	
MIL-STD-18.....	Structural Symbols	
MIL-STD-29.....	Springs, Mechanical.	
MIL-STD-34.....	Optical Elements	
MIL-STD-275....	Printed Wiring	
MIL-STD-806....	Logic Symbols	

Industrial Standards:

USAS B46.1 -62	Surface texture, roughness, waviness & lay
USAS Y14.5 -66	Dimensioning & tolerancing for engrg dwgs
USAS Y14.15-66	Electrical & Electronic Diagrams
USAS Y 32.2-67	Graphic Symbols for Elec & Electronic diagrams
USAS Y32.16-65	Electrical & Electronic Reference Designations
AWS STD A2.0-58	Welding Symbols
AWS STD A2.2-58	Non Destructive Testing-Welds.

Mil-Specs:

MIL-D-5480....	Data, Engrg & Technical, reproduction of:	(2)
MIL-Q-9858A....	Quality Program Requirements	(2)(3)
MIL-M-9868.....	Microfilming Engrg Dwgs	*(2)
MIL-I-45208....	Inspection System Requirements	(2)(3)
MIL-C-45662....	Calibration of Measurement & Test Equipment	(2)

MIL HDBKS:

H4-1...........	Federal Supply Code; Name to Code	
H4-2...........	Federal Supply Code; Code to Name	
H6-1...........	Federal Items Identification Guide	(2)
H7.............	Mfrs Part & Dwg Numbering System	(2)

Mil Manuals:

5220.22M.......	DoD Industrial Security Manual	(2)(3)
4120.3M........	Standardization; Policies, Procedures & Instructions.	

All the documents listed above are invoked by imposition of MIL-D-1000.Form-1.
(2) denotes Form 2 only.
(3) denotes Form 3 only.
* Only if Requ'd by CDRL

Figure 1

there can be wide variation in the merit of drawings produced to commercial/ industry standards or so it is believed within Government agencies.

1.1.2. The Drafting Practices Manual (DPM):

Over the years since MIL-D-1000 was first issued, the aerospace industry has developed DPMs. This has been done as a matter of necessity to ensure contractual compliance, and to inject a measure of uniformity into technical drawings. Contractors have become accustomed to responding to MIL-D-1000, Forms 1 & 2 and have costed their efforts accordingly. In actual practice, use of Form 1 has been limited, as not only are the costs high, but compliance with all of the Form 1 requirements is a time consuming, and tedious process. Facility drawings, which must for a very long time, & from the masters of which many copies must be made, have been made to the requirements of Form 1, as the legibility requirements are stringent. Form 3, with its broad latitude, has not been used often by either the DoD or the NASA; the customary Form invoked being Form 2. While the DPMs may vary to a minor degree, aerospace contractor to aerospace contractor, most of these manuals are very similar one to another, as they have been based upon Forms 1 & 2 requirements, particularly the provisions of MIL-STD-100A, Engineering Drawing Practices. To a large degree, the practices set forth in MIL-STD-100A have dictated what industrial practices for drawing production have become, since MIL-STD-100A is based upon accepted industry standards, and in many cases these are invoked in their entirety by the STD as dependency documents (See Fig 1). In effect, the DPM produced by any given contractor is submitted for Govt. agency approval as part of the contractor certification process, qualifying him to do business with the U.S. Government. Should the DPM not meet with agency approval, certification of the contractor can be with-held until the standard of drafting practice has been raised to the required level. As an outcome of these practices, even commercial/industry standards are not the lowest possible cost by any means. The cost situation is futher complicated by the fact that aerospace contractors, accustomed to doing business in the manner prescribed by MIL-STD-100A, to the Form and category stipulated in MIL-D-1000, are unlikely to produce drawings

which differ markedly from Form 2 standards, even though Form 3 is specified.

1.1.3. Cost Comparisons: Researches into the relative costs of producing drawings and lists in compliance with the three forms of MIL-D-1000 indicate that if drawings are produced to some basic cost figure compatible with the minimal requirements of Form 3; these same drawings will cost approx 40% more if produced to Form 2 requirements, and 75% more if executed in full compliance with Form 1. Other data suggest that some 47% of the costs to produce drawings to Form 1 requirements are incurred by the assurance processes involved in determining that the requirements have indeed been met.

1.1.4 The Least Cost Approach:

As has been stated previously, MIL-D-1000 Form 3 when imposed, does not necessarily assure the production of low cost drawings, particularly when the contractor producing the drawings is well accustomed to operating within the aerospace milieu. The fact that most of the military standard requirements cited in MIL-D-1000, MIL STD-100A, etc, have been derived from Industry standards, serves merely to produce drawings in which a relatively standard symbology, and set of drafting practices/techniques have been applied. For many drawings many of these techniques and practices are no longer necessary, nor are the 10 categories of MIL-D-1000 essential to the production of drawings which the Government can use. The elaborate nomenclature and numerology prescribed by MIL-STD-100A, came into wide use as an outcome of efforts to provide configuration management and control for aerospace programs. In the modern system of computer produced drawings and lists, such precautions are no longer necessary. Many drawings used in development phases of programs need not be produced using ruled lines. Frequently a free-hand rendition is sufficient provided suitable dimensions are furnished, and the drawing is legible. Similarly, 10 categories of drawings are not needed, since the drawings in most of the categories differ only in the particular symbology used. The optimum number of categories will be discussed in subsequent paragraphs of this document.

To summarize the measures believed to be essential for Least-Cost-Specifications governing Engineering Drawings and Lists, the following set of guidelines was developed:

- o Minimize the number of Drawing Categories.
- o Delete compliance with Military Standards and Specifications and substitute Industry Standards, using these as a reference and guide only.
- o Delete the requirements for Quality Assurance, with the exception of the inspection requirement for Count Identity and Damage, immediately prior to delivery.
- o Permit use of free-hand drawings in all cases where these will suffice.
- o Delete the requirements for reference to Military Specifications, dealing with tracing cloth and paper, as these are standard throughout the aerospace industry presently.
- o Delete the microfilming and reproduction requirements as a set of genal provisions. Most frequently these are unnecessary in today's technology, since in the case of most NASA programs fourth generation microfilm and a very large number of copies of drawings are not required.

1.2. Compiling the Drawing Specification:

1.2.1. Approach: With any new specification, there is an appreciable time lapse after its generation, and prior to its formal release. This interval allows the document to be circulated, so that potential users can become familiar with its provisions, requirements, and mandates. There is usually a period also during which comments, and recommendations for improvement/finalization of the document are furnished to the generating/releasing agency by the users. Since this document is novel in concept in that it sets aside many of the established means, and procedures for producing Government used drawings and lists, in favor of Low Cost methods; a different formatting approach has been adopted. Where considered necessary, each paragraph of the specification which follows, has one or more paragraphs of rationale.

These rationale statements, explain the underlying need for the preceeding paragraph, and the reasons why is is believed to represent a Low Cost approach to the subject under discussion/specification. The statements are arranged in such a manner that should NASA elect to publish the specification for use, the rationale can be omitted without any further change to the text of the document. Similarly, the historical preamble, and all foregoing text can be omitted without jeopardizing the meaning and application of the body of the specification. With all extraneous material of this type removed, the document can be implemented as a clearly defined set of contractually binding requirements with which contractors producing drawings for Government use must comply.

2.0. Specific Requirements:

2.1. Scope: This specification prescribes the requirements for the preparation of engineering drawings and lists, and for application of Intended Use Categories for their acquisition. The requirements reflect the desire of the Government to purchase legible drawings produced at the lowest price commensurate with their adequacy for Government use/purposes. The term Engineering drawings as used in this specification, incldes engineering drawings and associated lists.

2.2. Classification: NASA will acquire engineering drawings in one or more of three Use categories. These categories are listed as follows:

- o Design Descriptive/ Disclosive.
- o Procurement.
- o Installation & Maintenance.

2.2.1. Rationale: The three categories listed above replace the ten (10) categories of MIL-D-1000. In essence the appearance and symbology differ little among the 10 caegories. The differences lie in the use to which the drawings will be put. Since even these differences are ones of use, rather than technique, Design Descriptive/ Disclosive drawings will be inclusive of Categories A, B, & C of MIL-D-1000. Procurement Drawings will include categories, D,E,F & J, as the information on such drawings is quite similar per category, whereas Installation and Maintenance drawings will include categories G & H. Note that there is no inclusion of category I, as

In most cases, NASA does not manufacture prime equipment. This category was intended primarily to apply to Government Manufacturing agencies such as arsenals, producing a miscellany of armaments.

2.3. Applicable Documents:

2.3.1. One (1) Government document is imposed as a requirement by this specification. However, in cases where contractors have not furnished, hardware, software, materials, and services for the NASA; the following stipulations apply:

- o NASA will specify in the RFP that a Drafting Practices manual will be provided for NASA inspection and approval. In cases where such a document exists, it will be inspected by a NASA, or NASA designated government agency representative, technically qualifed, and empowered to approve the manual.
- o In cases where the contractor does not possess a DPM, such a document will be prepared, and submitted to the NASA for approval. Preparation will be undertaken using the following documents as a reference and guide:
    1. This specification
    2. MIL STD 100A, MIL-M-9868, MIL-D-5480 (For titles see Pg.3.)
    3. Industrial Standards:

        USAS B46.1-62 Surface Texture, Roughness, Waviness & Lay.

        USAS Y14.5-73 Dimensioning & Tolerancing for Engrg Dwgs.

        USAS Y14.15-66 Electrical & Electronic Diagrams.

        USAS Y32.2 -67 Graphic Symbols for Elec & Electronic Diagrams

        USAS Y32.16-65 Electrical & Electronic Reference Designations

        AWS-STD A2.0-58 Welding Symbols

        AWS-STD A2.2-58 Non Dstructive Testing-Welds.

2.3.1.1. Govt. Doc'mt: DoD Industrial Security Manual. #5220.22M (or NASA equivalents) This document will be specified only if work prepared is of a classified nature. In such cases, the document will be specified in the RFP, and also in the CIRL call-out.

2.4. Legibility & Reproducibility: Engineering drawings shall be of sufficient clarity that an original will reproduce not less than ten (10) legible copies when used as the master for such processes as Xerography, diazo-process, and white-print. Further copies may be obtained beyond 10 by repeating the process as many iterations as is needful, as these processes do not degrade the master original materially. For large numbers of copies, a photo process using a negative-positive method shall be employed. Blue-line drawing copies are not acceptable as deliverable items.

2.5. Drawing Methods:

2.5.1. Delineation: Lines need not be ruled in all cases. For drawings prepared under category A of this specification freehand sketches are acceptable, provided that sufficient detail is presented to allow hardware to be made from such sketches. Clarity of each sketch made shall be preserved as per para. 2.4., and dimensions shall be furnished to permit manufacture to essential tolerances.

2.5.1.1. Rationale: In engineering and development phases of programs, sketches are often sufficient to allow the manufacture of hardware whose function is to prove the viability of a design concept. It is NASA practice to purchase hardware rather than drawings, and in such situations the contractor is instructed to retain drawings on file. Sketches can effect an appreciable savings if used for all phases of a program except production manufacure and assembly.

2.5.2. Lettering and Line Formulation: For most drawings, pencil drawn lines are adequate. Ink shall not be used except for special processes where ink is a part of the process. Line weights shall not be varied except where essential to point out detail, but weights shall be sufficient to permit legible, clear reproduction. Lettering shall be freehand pencil characters, of simple Roman Block capitals and of sufficient size to permit clarity and legibility under photo-reduction processes. Italics shall not be used, except to highlight important statements.

2.5.2.1. Rationale: Lettering using lettering guides, templates, Leroy processes, and others require additional time. They do nothing for the drawing except add to the eye appeal. Drawings are a means to the production of operable hardware, and their artistic appeal is of no value in meeting this requirement.

An example of a special process requiring ink, is the generation of Master Layout drawings for Printed Circuit Board (PCB) production, where the process requires inking on Mylar, or other suitable high-plasticity material.

2.5.3. Automated Drafting & Mechanical Aids: Use of computers and associated devices to produce drawings is permitted in those cases where prior cost trade offs clearly indicate a marked cost advantage over manual methods. Variables to be considered in such a decision shall include, number of drawings of a given type to be produced, degree of standardization of such drawings, cost per unit drawing, inclusive of all program generation time, machine run time, etc., end use for produced drawings, and NASA stated requirements.

Mechanical Aids: Use shall be made of mechanical aids such as "Paste-Ups", transparencies, decals, and other transerrable symbols and characters, when such use offers a clear cost advantage over traditional methods. Implicit in the decision to employ mechanical aids of this type (these types), is the end use for the drawings to be produced.

2.5.3.1. Rationale: Machine produced drawings can be quite costly in terms of the set up and debugging costs of the programs which produce them. Similarly "Paste-ups" and other transferable media, are most useful when a set of drawings is to produce many copies in reduced sizes from an original. When instruction manuals, maintenance manuals, and other publications are to be produced, both computer methods, and mechanical aids used to produce "camera-ready" masters, can furnish significant savings.

2.5.4. Numbering System: The numbering system included in a contractor's DPM shall be employed for numbering drawings and associated lists. Wherever practical, such a numbering system shall consist of not more than 10 primary digits, and not more than 2 primary digits as dash numbers indicative of changes. The numbering system shall be as per NASA contractual instruction in the RFP or other document. Where a numbering system for a given program set of drawings is to be instituted for the first time, contractos shall use MIL-STD-100A as a reference and guide (Chapter 3 Numbering, Coding & Identification).

2.6. Drawing Detail & Views:

2.6.1. Drawing Detail: Multiple Detail dwgs shall be produced whenever feasible. The detail given shall be restricted only by the available space, and the clarity of the drawing.

2.6.1.1. Rationale: It is more cost effective, and less time consuming to provide as many details as feaible on a drawing rather than attach a number of sheets which furnish supporting detail.

2.6.2. : Supporting Drawings: Where supporting drawings on separate sheets become necessary, it shall be the practice to attach all supporting sheets to the top drawing, and number it as a package. The top drawing shall furnish the overall intelligence at the highest level practicable, and the sheets supporting this drawing shall furnish all required lower level, and ancillary data pertinent to the top drawing overall subject matter.

2.6.3. Drawing Views: Drawings shall be prepared using the minimum number of views commensurate with illustrating the detail of the device that the drawing depicts. In most cases,plan, and side elevations will suffice.

2.6.4. Drawing Scale: In all cases possible drawings shall be made to full scale, so that the subject delineated be represented as full size. Where full scale is not feasible, a scale shall be chosen that is as large as is feasible commensurate with sizing the drawing(s) for ease of handling, ease of storage, and maximum clarity.

2.6.5. Engineering Drawing Lists: Where the generation of lists is necessary to furnish data on parts, etc., such lists shall be included on the face of the drawing as practicable. Where lists are too voluminous for such a practice, they shall be appended to the drawing as a practical means of assuring their traceability/availability. Lists shall be simple typewritten documents on standard A size sheets, or shall be handwritten/lettered, if this is practical in the light of the amount of information to be included.

2.6.6. Drawing Titling & Margins: Elaborate margins shall not be used on drawings, nor are pre-printed elaborate drawing sheets in various sizes required. Titles shall be handlettered in a simple title block, which shall contain as a minimum, the drawing title, drawing number, and the signatory information, of originator, and checker.

2.6.7. Drawing Sign-Off/Approval: As a minimum, drawings shall be signed off by:

(a) The originator

(b) The checker

(c) The designer approving the drawing (if different from the originator)

Multiple drawing reviews by persons not directly concerned with either the production of the drawing, or the subsequent implementation of it during the hardware production phase of a program, is not required; and this practices is to be discouraged.

2.6.7.1. Rationale: Fewer signatories for each drawing produced, facilitates the release process by saving handling time, and hence costs.

2.7. Drawing Change Control: Drawing changes shall be kept to that minimum essential to ensure that an acceptable end product can be obtained from use of the drawing in question to secure that objective.

2.7.1. "Red-Lining": As changes become necessary, drawings shall be red-lined to permit rapid incorporation of the changes considered essential. When the change process is completed, a simple record shall be kept on the face of the drawing where this is practical, recording the extent and date of the Red-Line change made. Where the size of the drawing, or the scope of the changes to be executed, or both render this face record impractical, a simple system of recording by use of typed, or pencil-lettered, Design Change Notices will be inaugurated. These DCNs will be attached to the drawing which which they are associated, as part of the overall drawing package. When all changes have been incorporated on the drawing, a final fair copy will be prepared for final delivery to the customer if such is required contractually. Red-Lining, if used too liberally on a drawing, may tend to confuse the information contained thereon. Engineering judement is to be used, to limit the number of Red-Line changes inscribed. When the number of Red-Lined changes is such as to confuse the information, a simple Engineering Order (EO) will be issued requiring a new drawing, which incorporates all changes to date.

2.7.1.1. Rationale: The method of expeditious handling of drawing changes, while not directly a part of the processes by which drawings are produced, is a major factor influencing drawing update, release, and availability. Red-Lining, as a practice is well established, and facilitates rapid handling of changes, particularly for in-process manufactuirng drawings. Historically, Red-Lining has not been proscribed by either Category, or Forms 2 and 3 of MIL-D-1000, but tacit disapproval of the practice has been the accepted norm. NASA will specify in the RFP that Red-Lining IS DISALLOWED FOR A GIVEN PROGRAM/CONTRACT, SHOULD THIS DECISION BE TAKEN FOR ANY REASON BY THE NASA CENTER INVOLVED. In all cases where no such dis-allowance is specified, the practice is to be undertaken in accordance with the requirements of this specification.

2.8. New Symbology: In all cases where new symbology is developed, and required to be used for a drawing, or drawings, a detailed list of the new symbols contemplated for use, will be prepared and submitted to NASA for approval. Provisional approval to permit immediate use will be furnished within not more than 3 working days, and formal approval within 30 days of submittal of such a list.

2.8.1. Rationale: Symbology is dynamic in nature, as the state-of-the-art advances. Changes are particularly rapid in the area of electronic symbology, as LSI, MSI, and Hybrid techniques, become increasingly prevalent. Where new symbols are evolved, listed, and submitted to NASA for approval, NASA shall undertake the task of up-dating those documents listing current symbology, and imposing these on contracts.

2.9. Quality Assurance Provisions: Prior to the release of each drawing package, Quality Assurnace Inspectors/personnel shall inspect the package to determine that:

- o The correct number of drawings comprising the package is present
- o All changes have been duly incorporated, and that all drawings are correctly numbered and titled per the Engineering Drawing List (EDL)
- o No damage, defacement, or degradation of content has taken place.
- o That the package is in all respects ready for use/delivery to the customer.

A suitable inspection or QA stamp shall be affixed to the package, denoting that QA has approved the package for use/delivery. A Quality Assurance person shall sign the conveyance transferring ownership of the drawing package to the customer (NASA), i.e. Form D.D.250 or other, in the presence of the Government representative accepting the drawing package.

3.0 Preparation for Delivery:

3.1. Microfilm: Drawings which have been subjected to a microfilming reduction process, by contractual requirement, shall be packaged in a manner based on the provisions of MIL-M-9868; which document shall be used as a reference and guide.

3.2. Reproducible, and Non-Reproducible Drawings, Including Originals:
When delivery of such drawings is a contractual requirement, they shall be packaged for shipment and delivery in a manner based upon the methods set forth in MIL-D-5480. This document shall be used as a reference and guide for the preparation process.